The Vegetation of Maud Island, Marlborough, New Zealand

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Maud Island (Te Hoiere – "a long paddle or mighty pull") is a moderately sized island of 309 hectares, located in the Pelorus Sound (41° 02 ′S, 173° 54 ′E) Marlborough, at the north-east end of the South Island of New Zealand. It has a long history of human modification and impacts since its colonisation by Maori and early Europeans. The vegetation of Maud Island has been studied in the 1980's and again in the early 1990's. The objectives of this study were to (1) describe how the vascular plant communities vary in species composition across Maud Island, (2) determine which environmental factors are important predictors of the variation in species composition of Maud Island plant communities, and (3) describe the pattern of succession of the plant communities on Maud Island over the last twenty years. In this 2001 study, I comprehensively sampled the vegetation on Maud Island using a Reconnaissance Description Procedure in a total of 158 plots across the island and compared these results to previous descriptions. I also retook photos at permanent photo points to provide a visual comparison of vegetation change. In total, 219 plant species were identified; 177 species occurred within the plots and 42 additional species were observed while walking around the coastline and walking tracks. Six dominant plant species occurred in over 70% of the plots. They were *Pteridium esculentum, Pseudopanax arboreus, Hebe stricta* var. *stricta, Melicytus ramiflorus, Ozothamnus leptophylla* and *Coprosma robusta.* Two-Way Indicator Species Analysis resulted in the description of eight different plant communities on the island. Detrended correspondence analysis showed a high degree of turnover in species composition among these communities. Canonical correspondence analysis showed that slope and moisture were particularly important predictors of variation in plant species composition. The environmental factors that best predicted to variation communities were slope, moisture, and a gradient in historical disturbance. Comparisons of present and past vegetation maps and photos (ground and aerial) showed, in terms of the successional pathways of the vegetation on Maud Island, that over time, the vegetation is reverting from short stature grassland and scrub to predominantly forest scrub and young secondary forest.

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Chapter 1. Introduction

1.1 Plant Community Composition

Plant communities are rich, dynamic entities; their diversity, composition and spatial scale of variation, i.e., their structure, are driven by a range of factors. These factors, such as variation in abiotic conditions, human impacts, disturbance and predation have been studied since the 1800's across different landscapes, countries, and environmental conditions (Barbour, Burk and Pitts, 1980).

The role of factors such as climatic conditions, human disturbances including, grazing, fire, land clearance and fencing and the abiotic environment including, moisture, temperature, nutrients, litter, topography, slope and seed soil bank are seen as deterministic factors and are thought to play a driving role in structuring plant communities (Clements 1916, 1934; Barbour *et al.,* 1984; Crawley 1997). Moisture is often one of the major factors affecting plant community composition. Moisture may be affected by the soil type, soil depth, soil water holding capacity, atmospheric temperature, wind and altitude. Soil moisture content will affect mycorrhizal fungus, associations, soil pH, soil nutrients and invertebrates (Bellan & Vitt, 1995; Wardle, 1991).

Forest fragmentation due to land clearance removes plant biomass, can destroy seed soil banks, and open the forest up which will lead to higher temperatures in the interior, higher light levels, altered humidity and leaf litter moisture levels will be altered. Composition and structure of the forest will then be altered (Glenn-Lewin & van der Maarel, 1992; Fox, Taylor, Fox and Williams, 1997). Similarly, continual grazing pressure affects plant regeneration and soil fertility (McIntyre, Lavorel, & Forbes, 1999). The major cause of species loss and decline in abundance is land use change. Land abandonment and change in management practices will affect community composition, but species response to change will differ depending on environmental conditions and climate (Lindborg & Eriksson, 2005).

Grazing by herbivores can have an extensive impact on plant species composition. Grazing can increase the heterogeneity of plant cover distribution and may reduce plant species diversity (Alados *et al.,* 2003). For example Stewart *et al.,* found that reduction in browsing pressure as deer numbers decreased over a fifteen year period in Fiordland was the major factor in the recovery of the forest understorey (Stewart *et al.,* 1987). Removing grazing from an area that has had a long history of grazing will affect species diversity and some species will be negatively affected by the increased biomass which may affect the plant species invasion ability (Ranwell, 1960). Vinther (1983) found that woody seedlings could not establish in old abandoned mesic meadows due to the dense herb layer. While grazing by herbivores can impact on the vegetation they can also be responsible for seed dispersal in their hooves, faeces and coats. Abandoned pastures may also provide a higher fire risk (Wright, *et al.,* 1979).

Stochastic events such as fire, wind, and storms can affect the environment in many ways; fire may alter the soil structure and nutrient levels, destroy seed soil banks and therefore alter plant species composition. Despite multiple fires some plant species will survive and become fire tolerant, in time these species will dominate the vegetation and may displace the original vegetation. Fires as well have a short term impact on available light and higher nutrient levels and can enhance the chance of invasion of undesirable species (Zedler & Scheid, 1988). Storm events may cause erosion, and land slippage and wind may break down the forest canopy and open areas to invasive species (Glenn-Lewin & van der Maarel1992; Kent & Coker, 1996; Wardle, 1991).

Topographic gradients affect soil fertility and soil depth and thereby plant community composition. Soils in valleys and on the lower slopes are generally deeper and nutrient rich when compared to soils on higher slopes (Bartha, Collins, Glenn & Kertesz, 1995). In addition the area that a plant community occupies and the distance to other plant communities are two other key factors that can affect the plant community structure (Kent & Coker, 1996; Del Moral, 1999).

All these environmental conditions and historical and stochastic events are often important determinants of community structure and should be considered as they may affect the plant species that are present within a plant community. Although similarities are found among communities in similar environmental conditions, each plant community is unique to the place in which it occurs (Gleason, 1917; Glenn-Lewin & van der Maarel1992; Kent & Coker, 1996).

This multitude of mechanisms that can affect plant communities makes the study of the processes that cause the structure of a given plant community interestingly complex.

1.2 Island Community Composition

Due to their geographical isolation and small size, island ecosystems have a unique evolutionary history. Island ecosystems are fragile and are vulnerable to ecological and anthropogenic changes. Islands usually have lower habitat diversity, higher endemism and fewer species than comparable mainland areas, the extent of the differences depending on the time the island has been separated from the mainland and the extent of human disturbance (Timmins *et al.*, 1987; Simberloff, 1990; Wright and Cameron 1990; Saunders, 1994; Chapple *et al.*, 2001; Maunder *et al.*, 1999).

Islands frequently retain natural values that have been lost elsewhere due to the water barriers that separate them from the mainland. Islands are refuges for many plant species as they frequently possess species that are now largely, or entirely, confined to them (Simberloff, 1990; Hanski, 1982; Millar &Gaze, 1997). These plant species have undergone a strong selection process to survive and therefore are better-suited genetically to the habitat (Simberloff, 1990; Maunder, Culham & Hankamaer, 1999). One example of plant species surviving intensive modification is found on Philip Island, part of the Norfolk Island group. Vegetation on the island was decimated by rabbits for 150 years as well as by pigs and goats early last century. In 1986 all the rabbits were removed and the vegetation began to recover. Three endemic plant species thought to be extinct were found in subsequent re-monitoring programs, a grass *Leymus kingianum*, and two shrubs *Abutilon julianae* and *Hibiscus insularis* (Atkinson, 1998).

Island size is another important variable for plant community composition. Larger islands can support more individuals, meaning that species are less vulnerable to extinction due to stochastic or anthropogenic events (Hanski, 1982; Lofgren & Jerling, 2002).

Anthropogenic and stochastic events on islands cause changes in plant species composition and richness. The nature of these changes depends on the environmental conditions present on the island, and how those conditions have changed over time.

On many oceanic islands, the biota that existed before human colonisation has been highly modified by introduced pests, such as rats, mice, and rabbits, and human disturbances, such as grazing and fire. This means that the original ecological processes that structured those communities are likely to have been altered or destroyed. Many islands have suffered centuries of over-exploitation by humans; for example, Rapa Nui (Easter Island), where plant communities have not survived Chilean ranching; Gran Canaria, on which less than 1% of the original laurel forests have survived after land that was cleared for plantations and firewood; and Nauru, which has been totally transformed ecologically due to phosphate mining (Simberloff, 1990; Maunder, Culham and Hankamaer, 1999).

Fire and grazing has greatly affected the native vegetation on O'ahu – Hawaiian Islands. Fire promoted the growth of grasslands and small stature shrubs and increased the presence of exotic weed species (Woodcock, Perry and Giambelluca 1999).

In New Zealand, islands have a vital role in the conservation of endemic flora and fauna, providing refuges for 50% of our endemic frog populations, 6% of New Zealand's terrestrial vascular plants, and 37% of lizards (Towns, 1990). New Zealand is a land of many islands; from forest covered Stewart Island to small rock stacks of many parts of the coastline. New Zealand's islands can be placed into two categories: offshore islands that are less than 50 kilometres from the mainland, and outlying islands that are more than 50 kilometres. Offshore islands often used to be attached to the mainland and, therefore, species diversity is high and endemism is low, whereas on outlying islands endemism is high and species diversity is low. On offshore islands, historical human disturbance is high for example; Maori land clearance for pa sites and kumara growing, European slashing and burning for farming. The introduction of mammals, such as rats, pigs and goats, has caused many island habitats to be destroyed, or highly modified and endemic taxa to become severely reduced and fragmented (Atkinson, 1988; Maunder *et al.*, 1999; Chapple *et al.*, 2001).

1.3 Plant Community Succession

Succession is the process of change in plant community structure in an area over time. These changes are often complex and are affected by both physical and biotic factors. Disturbances due to abiotic and biotic factors are never evenly distributed over a time period or a landscape, which will result in a mosaic of different stages of succession over any given landscape (Whittaker, 1967; Townsend, Begon & Harper, 2003).

Succession of plant communities is driven by various, often interacting, factors which can include natural disturbance (e.g., fire, landslide); climate change, physiographic processes, human induced change through land clearance and farming practices, death of species due to natural processes, or the arrival of new plant species, or the to a seed source (Gleason, 1917; 1926; Whittaker, 1967). These factors, acting either singularly or together, cause change in the plant community structure over time. Changes may include an increase or decrease in plant species richness, change in plant species composition, an increase or decrease in nutrients and/or other changes in the overall structure of the ecosystem (Gleason, 1917; Whittaker, 1967; Townsend, Begon & Harper, 2003). The rate of succession may vary greatly; a community may persist for a very long time or it may be superseded quite quickly (Gleason, 1917; Whittaker 1967).

Succession is neither linear, nor predictable and will rarely reach equilibrium. Primary succession begins when the soil in an area has been removed by a catastrophic event or human intervention, and the soil removed. The plant community at this time is largely environmentally driven. Soil is generally depleted in nutrients, very shallow; it has poor structure and very little water holding capacity. Light levels are high which results in a higher photosynthesis rate and higher respiration rate (Walker, 1999). Primary succession results in an increase in plant biomass which leads to a differentiation of soil horizons increase in soil nutrients and an increase in plant species composition (Wardle, 1991). Plant species that invade these areas are early colonising species which are small stature shrubs and herbaceous species which are short-lived, nitrogen fixing, produce vast quantities of easily dispersed seed which is often wind dispersed and can reproduce vegetatively (Townsend, Begon & Harper, 2003; Walker, 1999).

Secondary succession is more common and may occur after land abandonment or after a disturbance that removes plant biomass, but there is no loss of soil (Saiid, 2001). In this situation, there are several invasions of plant species at different times (seral stages) and when disturbance reoccurs, the community composition may revert to an earlier seral stage (Gleason, 1917; Kent & Coker, 1996; Townsend, Begon & Harper, 2003). The frequency of disturbance events can have a major impact on how the original community does or does not recover. Depending on a given plant's autoecology, it may be many years before it sets seed again. If disturbances are close together the species that colonise the area will be driven by the life history traits of these plants. Over time plants that reproduce earlier on in their life cycle will dominate the plant community and may exclude and prevent regeneration of the slower reproducing plants (Noble & Slayter, 1980). Succession is influenced by plant species life traits, their ability to utilise the environment, their competitive ability, the type and magnitude of disturbance, distance of sources of colonists, the timing of the disturbance and the original vegetation type (Cook *et al.,* 2005).

The deterministic model of plant community succession, first introduced by Clements in the early 1900's stated that over time, assuming the community is not further disturbed, these early colonisers are replaced by more competitive species. These species are generally longer lived, taller, produce larger seed and are more tolerant of small scale disturbances. This series of replacements continues until some equilibrium is reached and a "climax community" of species that can continually reproduce and replace themselves remains (Clements, 1916; Kent & Coker, 1996).

The "climax community" is rarely, if ever, seen, as plant communities are always in a state of change. Change may be due to plants reaching the end of their natural life, invasions by other plant species, stochastic events, human disturbances and climatic variations. We can therefore see that disturbance and succession are inextricably linked. This means that in many systems, a climax community may never be reached (Gleason, 1917; 1926; Fernandez, 2004). Gleason's individualistic view of succession was not deterministic and emphasised the role of species' life history traits; their colonisation and persistence in a community is determined by how well-suited they are to the current environmental and biotic conditions.

1.4 Succession on Islands

The processes that drive succession on the mainland and islands are similar; however the impact of these processes on island plant community structure can be much greater. The coastline is very exposed to wind and waves making it a harsh environment to survive in. Whereas the centre of an island may be less exposed and will offer more sheltered sites for delicate plants. On islands, there is less variation in temperature; water can be restricted; slopes are often steeper; soil parent material is relatively restricted and hence soils have less diversity; and soils may have more soluble salts due to the salt-laden winds. These salt-laden winds may also have an impact directly on the plant species composition (Meurk & Blaschke, 1990). Timmins *et al.,* 1987) showed that the succession of vegetation on Mana Island (Wellington, New Zealand) was clearly being driven by aspect, and especially the salt-laden winds. Plant communities close to the shoreline were dominated by salt tolerant plants, such as New Zealand ice plant (*Disphyma australe*), New Zealand spinach (*Tetragonia trigyna*) and glasswort (*Sarcocornia quinqueflora*). In the more sheltered valley the predominant vegetation was broad-leaved scrub (Timmins *et al.,* 1987).

Succession may be slow and uneven due to competition from the existing vegetation and a small depauperate seed bank. Species richness is affected by the seed bank which is present in the soil, the existing vegetation and plant species in the surrounding area. Studies have shown that secondary succession is affected by timing which is linked to seed availability. If the seed soil bank has been removed there is a long term effect on plant species composition within an area (Wardle, 1991; Pakeman and Small, 2005; Howe and Mirti, 2004).

In New Zealand islands have a vital role in the conservation of our endemic flora and fauna. Due to their isolation islands have often retained natural values which have been lost on the mainland. Many of these islands however need some degree of management to ensure that the flora and fauna can survive. At present approximately ninety New Zealand Islands have undergone some form of management to aid restoration of the ecosystem. This has been achieved predominantly by removing mammalian predators, removing grazing animals and allowing the islands' ecosystems to regenerate naturally (Towns, Daugherty, & Cromarty, 1990; Robinson & Handall, 1993).

Examples of islands in New Zealand that have had some management are Enderby were cattle were removed in 1991 and rabbits in 1993. Campbell Island were sheep and cattle were removed from 1983 to 1991. On Enderby Island Cockayne in 1903 and Taylor in 1971 both noted that the rabbits were having a serious effect on herbaceous species and cattle had almost eradicated the native tussock *Poa litorosa*. Cattle had also had a serious impact on the bush areas and the grazing of the cattle was preventing regeneration of most species. Monitoring of the natural succession of the vegetation recovery was not monitored until the late 1990's. Monitoring showed that *Poa litorosa*, *Stilbocarpis polaris* and *Anisotome latifolia* which all had restricted distribution was invading many other areas of the island (Brown, 2002). On Campbell Island the effect of grazing from the introduced animals was first noted as early as 1907. Since that time many scientists have visited the island and noted a decline in the *Dracophyllum* scrub, a decrease in the sub-Antarctic mega flora and an increase in the unpalatable grass *Poa litorosa*. After the eradication program began Meurk in1982 noted "dramatic changes" and "vigorous" natural regeneration of many plant species. Photo-points and transects have been set up to determine natural succession over time (Brown, 2002). Maud Island in the Marlborough Sounds is another example of an island where removing grazing pressure and fencing has allowed natural regeneration and therefore succession of plant communities to occur. This study choose to study the natural regeneration of the vegetation on Maud Islands as the island is used by the Department of Conservation (DoC) as a safe habitat for Kakapo and Takahe. While several studies have identified some of the communities on Maud Island DoC wanted an in-depth current report on the vegetation know present on Maud Island.

1.5 Maud Island

Maud Island (Te Hoiere – "a long paddle" or "mighty pull") is a moderately sized island of 309 hectares. Maud Island is located in the Pelorus Sound (41° 02 ′S, 173° 54 ′E) (Figure 1.1) Marlborough, at the north-east end of the South Island of New Zealand. On the north-east side of the island (Te Paka Point) there is only 900 metres of water (Apuau Channel) separating the island from the mainland (Brown, 1996).

Maud Island is managed by the Department of Conservation their objective is to maintain and enhance Maud Island as a special area for the management of protected fauna and flora (Brown, 1996).

All of Maud Island except for the sea cliffs was covered in forest before human habitation. The first colonisers –Maori only cleared small areas of land on the north-western side of the island. Evidence of this can be seen on the north-west side of the island where there are several pit sites and midden sites near the septic tank of the caretaker's house (Brailsford 1997). It is not known to what extent Maori altered the vegetation or if they brought any plants to the island. Although, there is a strong possibility that Maori bought karaka *(Corynocarpus laevigatus)* and possibly kumara to the island as food sources.

Maud Island has had a long history of European occupation, beginning in the 1800's. Since then the island has suffered intense modification, including the original land clearance for farming (Figure 1.2), fence and track building, and construction of buildings such as the original farmhouse (subsequently destroyed by controlled fire), and several defence structures built by the army to counter any Japanese invasion during WWII (Figure 1.3) (McCaskill, 1981; Ogle, 1982; Brown, 2000).

In 1970, W. Shand (the then owner) made the house bush a private scenic reserve named the Tom Shand Reserve. A year later, Shand gifted the house bush area to the Crown for the preservation of flora and fauna and in 1972, gifted another 62 hectares to the Crown to add to the reserve. In 1975, Shand approached the Crown regarding the purchase of the rest of the island. This was agreed and achieved by public subscription. The management of the island from this time was administered by the Wildlife Department until being transferred to the Department of Conservation (D.O.C.) in the late 1980s. Maud Island is now a scientific reserve and landings are restricted to the resident caretaker, D.O.C. staff and a few scientists. A more explicit history of Maud Island can be read in Appendix 1.

1.5.1 *Fauna*

At present Maud Island is home to several rare and endangered animal species including Hamilton's frog (*Leiopelma hamiltoni*), the large land snails (*Powelliphanta hochstetteri*), Cook Strait click beetle (*Amychus granulatus*), giant weta (*Deinacrida rugosa*) and the introduced takahe (*Nortornis mantell*).

Given the long period that Maud Island was farmed, it is surprising that rodents and other introduced pests including possums have not become established on the island. Possums (*Trichosurus vulpecula*) were never released on Maud Island. Over the years, stoats (*Mustela erminea*) and red deer (*Cervus elaphus*) have swum to Maud Island from the mainland but were eradicated. According to Atkinson and Taylor (1991), pigs (*Sus scrofa*), goats (*Capra hircus*), rabbits (*Oryctolagus cuniculus cuniculus*), cattle (*Bos* sp.) and sheep (*Ovis* sp.) have all established populations on Maud Island, mainly due to human activities (Atkinson and Taylor, 1991; Ogle, 1982). However, all these species have been eradicated except for a few sheep, which graze grassland areas also utilized by takahe at the time of this study .Other bird species on the island include; tui (*Prosthemadera novaeseelandiae*), silvereye (*Zosterops lateralis*), fantail (*Rhipidura fulginosa*), bell-bird (*Anthornis melanura*), rifleman (*Acanthisitta chloris*) and large numbers of kereru (*Hemiphaga novaeseelandiae*). Introduced bird species include: blackbird (*Turdus merula*), song thrush (*T. philomelos*), starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and chaffinch (*Fringilla coelebs*). The little spotted kiwi (*Apteryx owenii*) was released on Maud Island but failed to survive. In addition, weka (*Gallirallus australis*) was released on the island between 1945 and 1955; they have now been eradicated and any that swim to the island from the mainland are destroyed.

The island has a very rich invertebrate fauna, which at present has not been studied in detail. There are possibly some endemic invertebrates that have not yet been described (N.Z.W.S, 1985). Lizard species recorded on the island include *Holodactylus maculatus*, *H. granulatus*, and the vulnerable Stephen's Island gecko (*H. stephensis*) (Brown, 1996).

1.5.2 *Flora*

The ecosystems on Maud Island are highly modified and degraded due to over 135 years of intensive farming. There are three remnant patches of lowland broadleaf/podocarp forest on the island. While these patches of bush are relatively pristine, they have been modified to some degree by gazing by sheep, cattle and pigs.

At 15 hectares, the main bush above Comalco Lodge is the largest of the three bush remnants; the other two small areas include one in Boat Bay and one on the north-west side of the island. The main bush forms the catchment for a spring, which surfaces in the grassland below Comalco Lodge. The dominant canopy tree in the bush remnants is *Dysoxylum spectabile* a spreading tree which is often the major component in coastal forests from North Cape to Nelson (Ogle, 1982; Salmon, 1986). This is interesting, because on the adjacent mainland areas and other islands near Tennyson Inlet, *Nothofagus* sp. is the dominant canopy tree. Direct evidence has not been found to determine if *Nothofagus* sp. was present or not on Maud Island (Ogle, 1982).

Other vegetation areas include two small pine plantations and several pasture areas. The areas in pasture are maintained for introduced species, e.g., takahe whose preferred habitat is grasslands. The remainder of Maud Island is made up of several regenerating areas of scrub and grasslands. The scrub patches are at various stages of succession dependent on when burning ceased and when they were fenced which removed grazing pressure (Gray, 1977; McCaskill, 1981; Ogle, 1982).

Several plant species on Maud Island reach their southern extremity; these include *Knightia excelsa* and the uncommon *Streblus banksii* which is represented on the island by one large tree and several seedlings growing near the seashore in Milk Tree Bay (Salmon, 1986; David Given, *pers. comm.*, 2001). Plants grown from the rare plant, *Hebe speciosa*, whose last remaining natural location is at Titirangi Bay, Marlborough Sounds and the locally uncommon *Aciphylla squarrosa* (Cook Strait spaniard) have been planted on Maud Island (McCaskill, 1981; N.Z.W.S., 1985; Brown, 1996; Brown, 2000).

Deliberate plantings of mainly exotic plant species took place many times on Maud Island. These include the planting of an unknown quantity of *Chamaecytisus palmensis* in the 1970s along parts of the Ring Road and the fence-line between the main bush and the house paddocks and the planting of another 200 trees in 1981. *C. palmensis* was planted to encourage bird life, particularly kereru (B. Bell, *pers. comm.*, 2001). In the 1970s and 1980s, wildlife rangers threw handfuls of *Lotus pedunculata* seed all around the island. *Metrosideros excelsa*, an endemic northern North Island plant, has been planted along the foreshore beside the wharf and on the cliff edge adjacent to the gun emplacement. This species is outside its natural range and over time could spread and become a weed. Several thousand *Coprosma repens* (taupata) were planted over several years to act as fire breaks and supplementary bird food (Peace, 1979).

1.6 Aim and objectives

This study aimed to characterise the plant communities on Maud Island and their history of development over the last 20 years. The three specific objectives of this study were to (1) describe how the vascular plant communities vary in species composition across Maud Island, (2) determine which environmental factors are important predictors of the variation in species composition of Maud Island plant communities, and (3) describe the pattern of succession of the plant communities on Maud Island over the last twenty years.

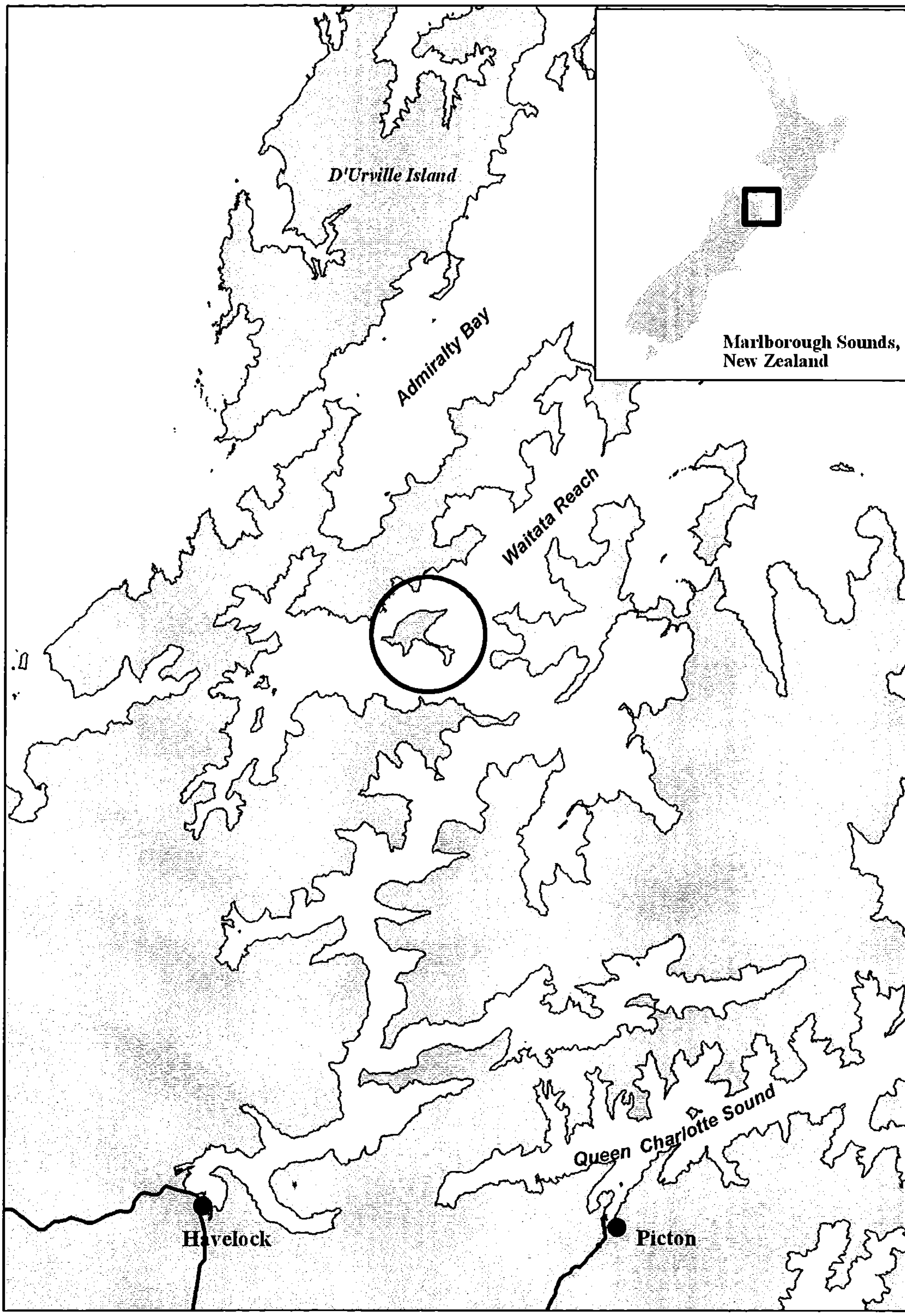


Figure 1.1: Location of Maud Island in the Marlborough Sounds of New Zealand.

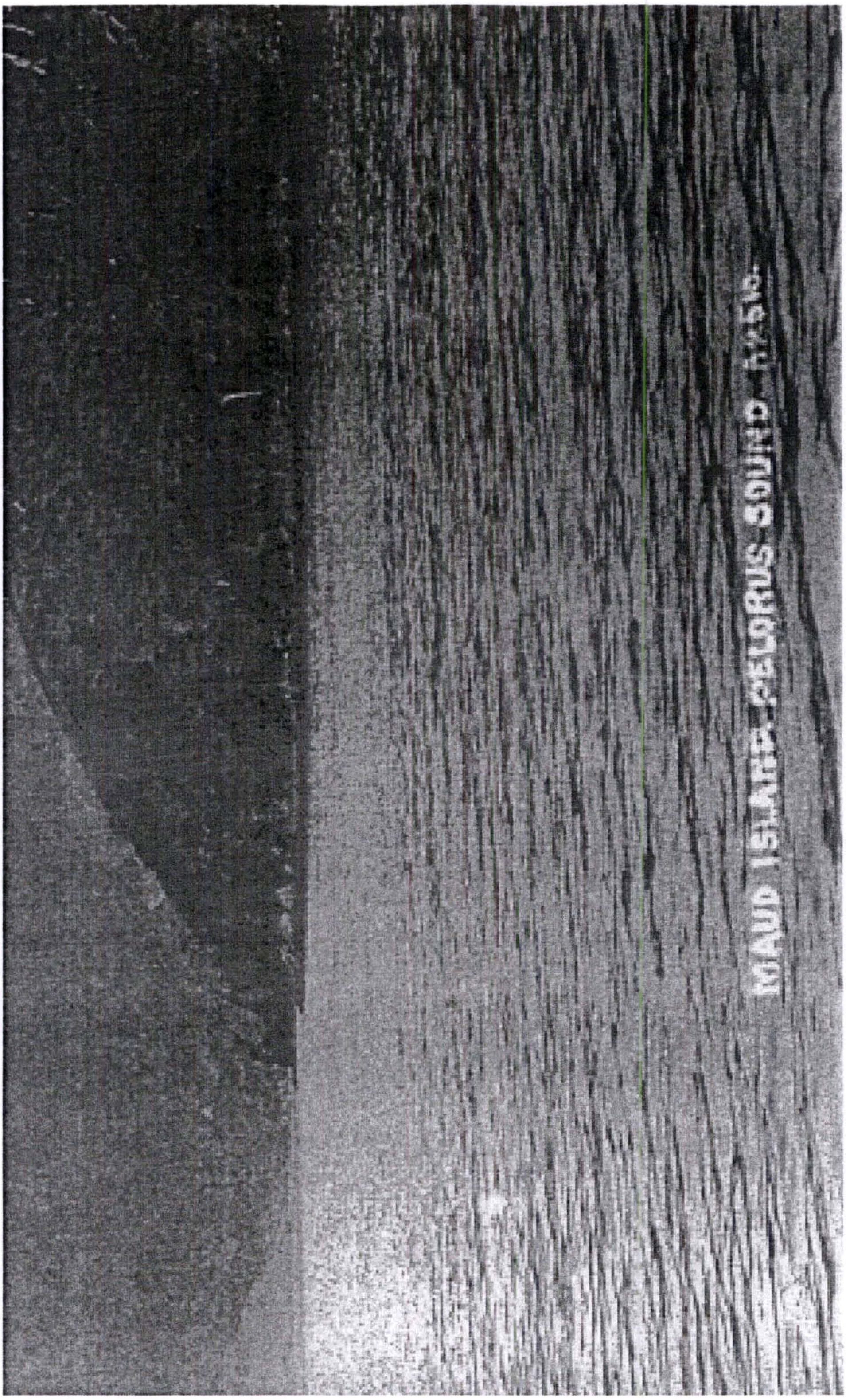
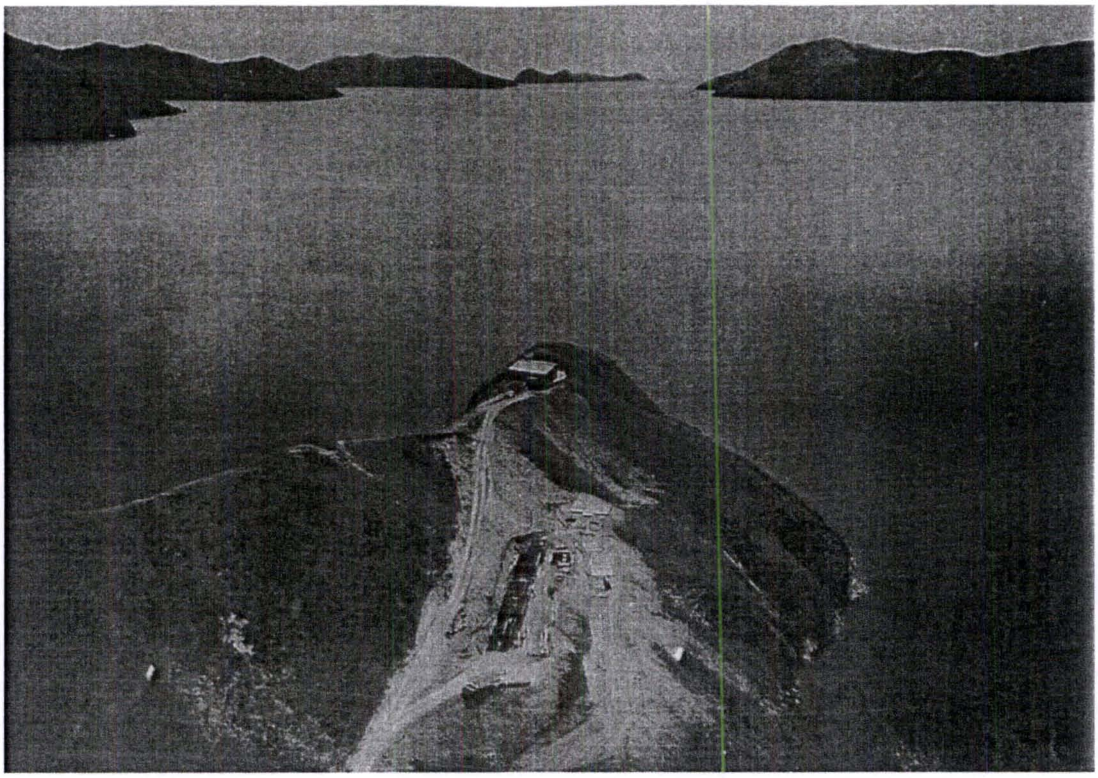


Figure 1.2: Land Clearance on Maud Island (Aldersly, 1913).



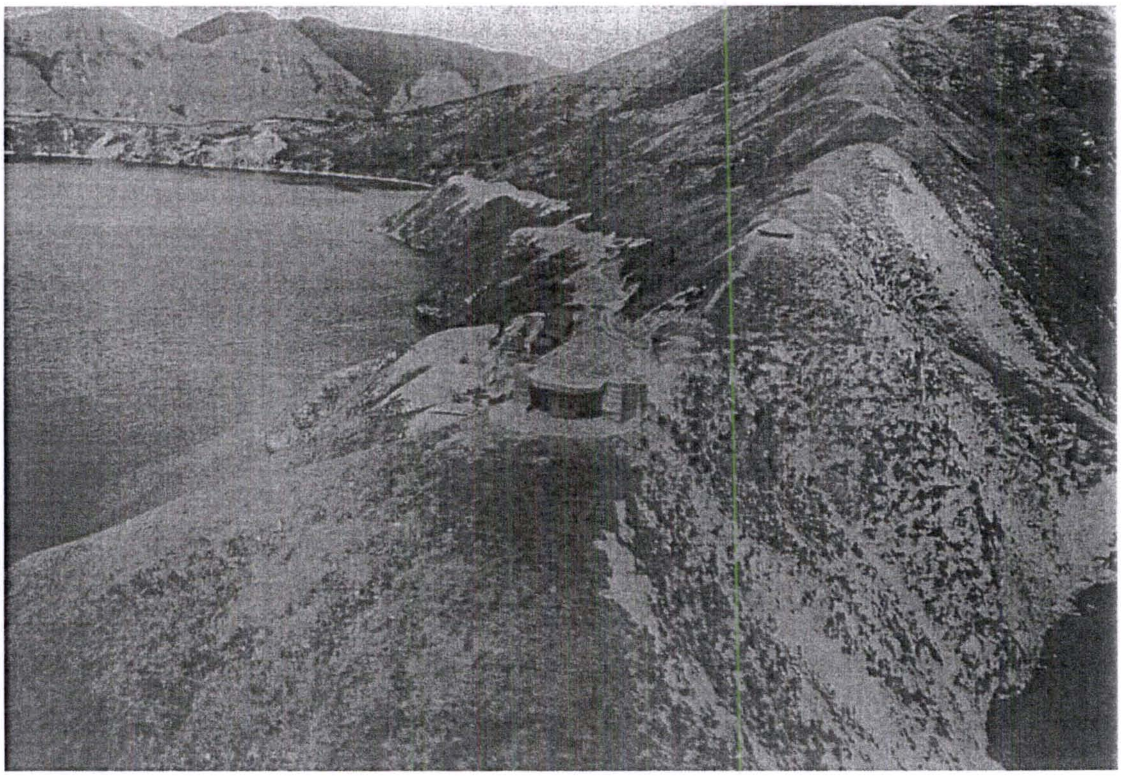


Figure 1.3: Gun battery and military buildings, Fort Point, Maud Island, 1940's (H.G.S.C. 1996).

Chapter 2. Methods

2.1 Physical Description of Maud Island

The Marlborough Sounds are part of a drowned river valley system that is dominated by mountain slopes and steep hills (Walls and Laffan, 1986). The topography of Maud Island reflects this. A central conical peak (370 metres) dominates Maud Island with steep slopes (most are greater than 28 ^{o}) that descend directly to the sea. The peak is the highest point of a narrow north-east to south-west ridge, which ends abruptly in two southern headlands and one northern headland. Along the eastern flank of the island, a fourth headland terminates into a long peninsula, which is connected to the main part of the island by a long, narrow isthmus (Beck, 1964; Webb and Atkinson, 1982).

Geologically, Maud Island is made up of stable Carboniferous and Permian age pillow lavas, red and green volcanic argillite, greywacke and conglomerate (Beck, 1964). Soils on Maud Island are typical of the outer western coast of the Marlborough Sounds. Webb and Atkinson (1982) classified the soils on the island into five main types (Figure 2:1): (1) Ketu steepland, soils firm phase, (2) Ketu hill, soils firm phase, (3) Ketu steepland, soils friable phase, (4) Ketu hill, soils friable phase, (5) Ketu hill, soils clay loam phase. These soils are moderately fertile and in the undisturbed forest sites the steep slopes are characterized by stony profiles. The major factors affecting the soil pattern are: the rate of erosion, which is influenced by the topography (slope angle and slope position) and the moisture of the soil, which is influenced by aspect. Erosion has affected the availability of parent material for soil formation (Webb and Atkinson, 1982) and is confined to the steep coastal slopes and the more exposed areas. In places erosion has been aggravated by human disturbance and grazing (N.Z.W.S, 1985).

Predominant winds on Maud Island are west to north-west, but these winds bring little rain as the Marlborough region is sheltered from heavy rainfalls by the North Island. The annual rainfall of 900-1200 millimetres is evenly distributed over the year although occasional droughts do occur. There are no abrupt seasonal changes in the weather; summers are warm and winters are mild (Pascoe, 1983).

2.2 Data Collection

Field data collection occurred in the summer 2000-2001. Summer is considered the best time to survey plants, as most plants are in flower at this time and are therefore easier to identify. A CD containing all data associated with this study is attached to this thesis.

The vegetation of Maud Island was systematically sampled using parallel transect lines at 200 metre intervals starting at the north-east (gun emplacement) end of the island. Transect lines commenced and finished as close to the sea as possible, using a 325° compass bearing going up the hill and a compass bearing of 145° on the return transect. Plots were located along each transect line at 100 metre intervals, including a plot at the beginning and at the end of each transect line (Figure 2.2).

The same arrangement of parallel transect lines at 200 metre intervals was used on the peninsula, starting at Harter Point. Transect lines started and finished as close to the sea as possible using a transect line on a 235° compass bearing going up the hill and a compass bearing of 55° on the return transect. Plots were located along each transect line at 100 metre intervals, including a plot at the beginning and the end of each transect line (Figure 2.2). On the narrow isthmus of the peninsula, one transect line was located along the ridge top. Plots were located along this transect line at 100 metre intervals alternating left to right, including a plot at the beginning and at the end of each transect line. At total of 158 plots were established.

The sizes of the plots were: 20 × 20 metres for plots with trees over 5 metres tall, 10 × 10 metres for plots with trees and shrubs 30 centimetres to 5 metres tall and 5 × 5 metres for grassland plots. Barbour, Burk and Pitts (1980) recommended these minimal area sized plots from previous vegetation sampling. They found that different vegetation types, e.g., forest, shrubland and grassland, required a different plot size to ensure 95% confidence that all plant species had been sampled (Barbour, Burk and Pitts, 1980).

In each plot a Reconnaissance Description Procedure (RECCE) was carried out (Allen, 1992). RECCE descriptions are simple and effective records of vegetation within a homogenous area. They were developed for use in New Zealand and form a key part of the National N.V.S. database (G. Walls, *pers. comm.*, 2003). For each plot a modified RECCE sheet was used (Allen, 1992).

Within each plot the presence of all plant species was recorded in seven physiognomic tiers. These height/vegetation classes were determined by the occurrence of the major growth forms on Maud Island:

(1) Tree tier: canopy and emergent trees in the main canopy greater than 25 metres.
(2) Sub-canopy tier: trees and tree ferns in the sub-canopy 12 -25 metres.
(3) Sub-canopy tree and shrub tier: trees, tree ferns and woody shrubs 5 -12 metres.

(4) Shrub tier: woody shrubs 2 metres-5metres.
(5) Shrub, herbaceous tier: shrubs and herbaceous species 30 centimetres-2 metres.
(6) Herbaceous tier: herbaceous species and woody seedlings less than 30 centimetres.
(7) Lianes and epiphytes: lianes, woody climbers or vines, epiphytes, plants growing above the ground surface on other plants.

The percent cover of all trees and shrubs was visually estimated in six cover classes (<1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-100%), which commonly adds up to more than 100% in plots (Allen, 1992). The percent cover of different types of ground cover was recorded in each plot: litter, including logs and branches, non-vascular plants, rock, and exposed soil (Allen, Rose, Evans, 1983; Stewart and Harrison, 1987; Allen, 1992). The mean top height of the dominant canopy cover was recorded for each plot. Species were recorded using the first three letters of the genus and the first three letters of the species. Any other incidental information, such as recent disturbance or heavy grazing was also recorded for each plot.

The environment of each plot was characterized by recording the following variables for each transect and plot: altitude, aspect, slope, physiography, soil type, surface characteristics, drainage, culture influences, browse and ground cover. Appendix 2 contains a complete list of the variables and how they were measured.

At each plot location a G.P.S. point was recorded using a Trimble 8 channel Pro XL G.P.S. This was essential for the construction of a vegetation map. Differential corrections were applied to each point recorded by using the G.P.S.

2.3 Data Analysis

A combined approach using classification and ordination was taken to characterise the plant communities on Maud Island. This methodology is valuable in revealing the strength and direction of relationships between species composition and other measured variables, because it combines the usefulness of classification for summarisation with the effectiveness of ordination in identifying gradients and relating multiple variables in one analysis (Gauch and Whittaker, 1981; Carleton, Stitt and Neppola, 1996).

2.3.1 *Classification: Two-way Indicator Species Analysis (TWINSPAN)*

Initally, both species presence data and cover data were classified using Two-Way Indicator Species Analysis (TWINSPAN) in PC-ORD for Windows, Version 4.0

(McCune and Mefford 1999). Species presence data gave a clearer separation of the plant communities on Maud Island and are therefore presented in this thesis. TWINSPAN uses a polythetic divisive technique of indicator species analysis resulting in a two-way ordered table of plant species and plots from a site-species matrix based on floristic composition (i.e., species presence/absence) (Hill *et al.*, 1975; Leathwick, 1987). This divisive technique creates divisions by working downwards then dividing the data into similar sized groups. Each group can then be characterised by a certain vegetation composition, the so-called vegetation type (plant community). I accepted the 4th level of TWINSPAN divisions that resulted in a classification of the plant communities on Maud Island. Giving me 8 vegetation types. Ogle had classified the vegetation into 16 vegetation types. I did not divide my data into 16 vegetation types as beyond 8 vegetation types the data was too similar and would have given a false picture of the vegetation types of Maud Island.

Community names were constructed using the three plant species of the highest percent cover in rank order as the community name, e.g., *Macropiper excelsum - Dysoxylum spectabile - Rhopalostylis sapida.*

2.3.2 *Ordination*

Species presence and environmental data were ordinated using the multivariate statistical package CANOCO for Windows Version 4.5 (ter Braak & Šmilauer 2002) Ordination results in diagrams where plots that are more similar in species composition are clustered together (Lepš & Šmilauer 2003), giving a graphical representation of the variation in species composition in plots across Maud Island that is easy to interpret.

Initially, to examine the variation in species composition across plots, I used detrended correspondence analysis (DCA) to ordinate the entire species dataset. If detrending had not been used, an arch effect (where plots that are very dissimilar in species composition are placed closer together on the ordination diagram) would have been likely to result because the gradient lengths were greater than four (Kent & Coker, 1996). Detrending is done by segmenting the data along the first axis then recalculating the second axis so that the points along the second axis are expressed as deviations from a mean of zero (Kent & Coker, 1996).

Because this initial ordination was heavily influenced by the presence of rare species and plots that were outliers in terms of species composition, resulting in an ordination diagram that was difficult to interpret, I reanalysed a reduced species dataset consisting of only those species in greater than 2% of plots and excluding the two plots that consisted only of *Pinus radiata*; this dataset contained 98 species in 156 plots.

I used one of the most common methods of direct gradient analysis, canonical correspondence analysis (CCA), to relate variation in environmental conditions to variation in species composition for the reduced dataset (Lepš & Šmilauer 2003). CCA regresses environmental factors, which are likely to be linked to underlying resource gradients, to species composition using multiple regression within the ordination (Kent & Coker, 1996). Environmental variables for plots included in the analysis were log-transformed percent cover of rock, percent cover of soil, percent cover of litter, square-root transformed altitude, presence or absence of moss, aspect, and slope.

2.4 Comparison of Current Communities with the Historical Records

The exact methods used by Ogle and Dix were not replicated in this study. The method Ogle used is described in Atkinson 1982. The objective of this survey was different to Ogle's and required a more quantitative approach. In addition this study surveyed more of the island than the previous studies. Therefore it did not permit accurate comparisons between the previous surveys. But by comparing the previous surveys with this study it allowed us to give an indication of how the vegetation on Maud has changed over time.

Permanently marked photo-points are useful for comparing vegetation changes over time. In 1990 Dix took a series of photo-points; in this study I re-took these photos as close to the original point as possible. In addition, I took a G.P.S. (Global Positioning System) position at each photo- point to permanently record its position enabling future studies to replicate this work.

2.4.1 *Constructing the vegetation map*

Control System (Trimble Navigation, 2000). ArcGIS version 9.0 software was used to analyse the data captured in the field using the G.P.S. and to produce a vegetation map. To achieve this, the differentially corrected G.P.S. data were imported as a table into ArcGIS version 9.0. The software utilizes the coordinate information in the table to display the data as a point theme. Each point is associated with a record in the table allowing access to attribute information. This point theme was then overlaid onto a georeferenced digital aerial photographic (J.P.G.) file of

Maud Island. Community boundaries were drawn on the map using the assigned Twinspan communities.

The plant community map that Colin Ogle drew in 1980 on a visit to Maud Island was scanned into ArcGIS version 9.0 and georeferenced to the 2001 vegetation map of Maud Island created in this study as described above. Due to differences in spatial scale the two images did not line up exactly there was an approximately 15 metre (positive or negative) difference. Despite this slight deviation, comparing the maps digitally enabled me to accurately determine the differences in community classification, and therefore, vegetation change over time, at the sampled points. I did not use J. Dix's map because it was based on fewer plots and observations and therefore was of lesser accuracy than the other two maps, making quantitative comparison impossible.

The comparison of these vegetation maps gives us a clear indication of how the vegetation on Maud Island has changed over time.

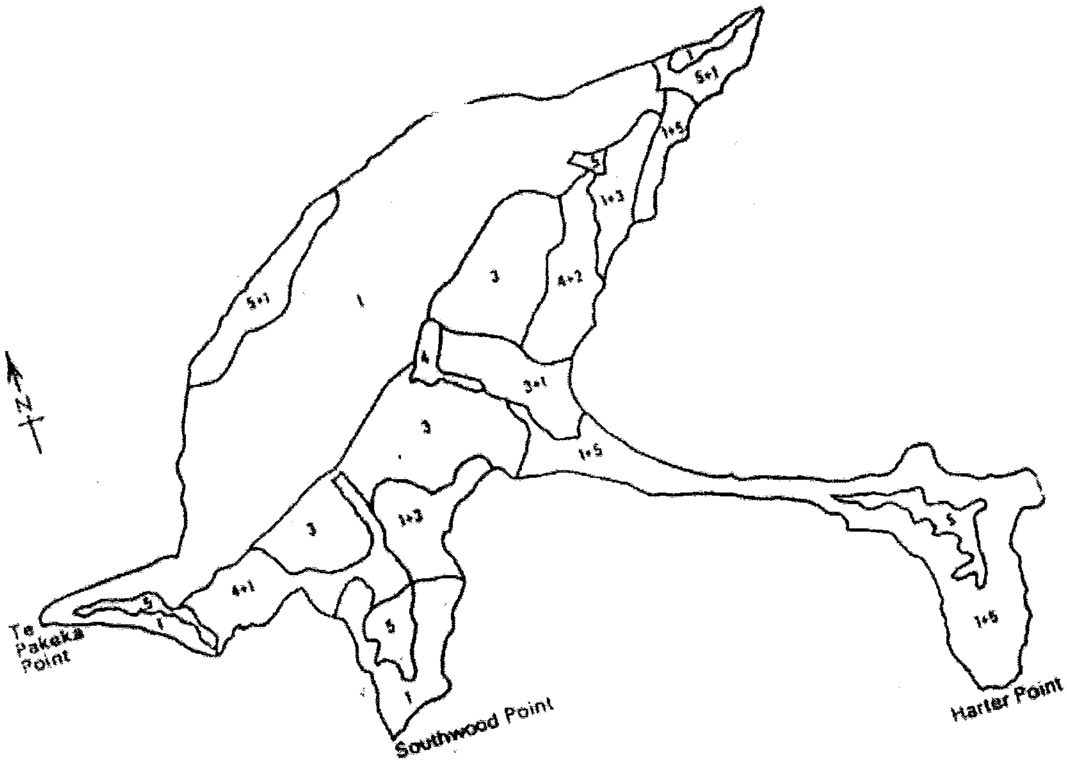


Figure 2.1: Soil map of Maud Island: 1 – Ketu steepland soils, firm phase. 2- Ketu hill soils, firm phase. 3 – Ketu steepland soils, friable phase. 4 – Ketu hill soils, friable phase. 5 – Ketu hill soils, clay loam phase (Webb and Atkinson 1982).

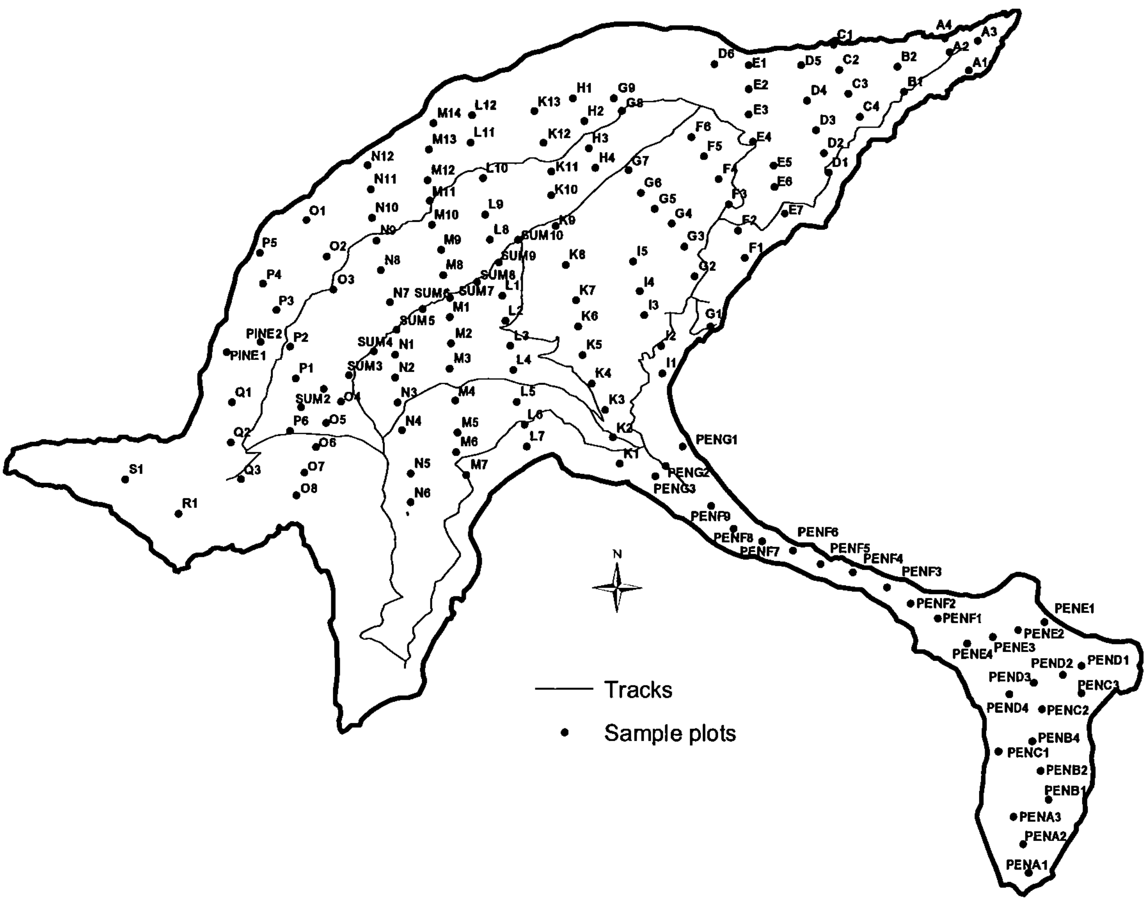


Figure 2.2: Map showing the locations of the 158 plots established on Maud Island in this study surveyed in the summer 2000-2001. Note that not all areas were surveyed due to the presence of Kakapo.

Chapter 3. Results

3.1 Plant Community Description

3.1.1 *Species richness and relative abundance*

In total, 219 plant species were identified on Maud Island. Of these, 177 species occurred within the 158 plots and 42 additional species were observed while walking around the coastline and walking tracks. This included a new plant for Maud Island, *Plagianthus divaricatus* which was observed growing on the southern coastline. Native species comprised the majority of the flora with 152 (69%) species, compared to 67 (31%) exotic species. When broken down by growth form, herbs and of the flora were trees and shrubs, and the numbers of ferns and fern allies were lower, at 43 species (19%). A full species list is given in Appendix 3.

Within the plots, the six most common plant species were: *Pteridium esculentum*, *Pseudopanax arboreus*, *Hebe stricta* var. *stricta*, *Melicytus ramiflorus*, *Ozothamnus leptophylla* and *Coprosma robusta*. The high percentage of *P. arboreus* was mainly due to the high abundance of seedlings in many of the plots. *P. esculentum* was found in all but three of the plots, an indication of disturbance due to past farming practices, such as burning (Wassilief, 1982). Most of the species were rare, with 96 plant species occurring in less than 3% of plots.

3.1.2 *Classification of plant communities using Two-Way Indicator Species Analysis (TWINSPAN)*

TWINSPAN initially divided the plots into two structurally different groups: forest/scrub and pasture (Figure 3.1). However, I terminated the TWINSPAN at the fourth division, which resulted in eight community types (Table 3.1). When environmental variables were summarised for the plots grouped into the eight communities, distinct differences among plots in environmental conditions were revealed (Table 3.2). Although there is a plant community distinctive to the shore, it was not sampled in this study because much of the coastline of Maud Island is very steep, making access difficult and even impossible in many areas. However, a walk along the coast was undertaken and all novel plant species were noted and added to the total flora list (Appendix 3).

3.1.3 *Description of the vascular plant communities of Maud Island*

Species composition within the plant communities varied markedly between different areas on Maud Island and was constrained by several environmental factors.

Community descriptions and an interpretation of how the environmental factors may have affected these communities are given below.

Community 1: Pine Plantations

Only two plots were sampled within the pine plantations. In both cases the only species was *Pinus radiata*. The high litter content, low percentage of exposed soil and the low light due to dense vegetation cover within this community may be impediments to regeneration of native species.

Field observations revealed that the large pine plantation near Te Paka Point had a small area within it that had not ever been planted in pines; the reason for this is unknown. This area supports a community of lowland scrub that is regenerating well and slowly encroaching into the nearby plantation as the pines mature and the canopy thins out. In the plantation there is a damp gully which has ferns and several seedlings of the main canopy trees, such as *Dysoxylum spectabile* and *Beilschmiedia tawa,* growing within it.

Community 2: Forest

Ninety-six species within 19 plots were classified into the forest community. The dominant canopy species were *Dysoxylum spectabile* and *Rhopalostylis sapida*, which are both typical of coastal forest plant communities at this altitude. The sub-canopy included *Macropiper excelsum*, *Beilschmiedia tawa*, *Cyathea medullaris*, *Carpodetus serratus*, *Knightia excelsa*, *Corynocarpus laevigatus*, *Laurelia novae-zelandiae*, *Pseudopanax arboreus*, *Melicytus ramiflorus* and *Alectryon excelsus*. These plant species associations are characteristic of mixed species lowland coastal vegetation (Cockayne, 1967; Allan, 1982; Wardle, 1991). At lower altitudes the main forest above Comalco Lodge was dominated by impenetrable stands of *Freycinetia banksii.* In the forest at Woodlands Bush there were numerous seedlings of the uncommon *Streblus banksii,* along with a few adult trees. The predominant lianes in all the forest plots were *Metrosideros diffusa* and *Ripogonum scandens*. This community had the highest average tree height (15.5 meters).

Twenty percent of the plant species in this community were ferns, the highest total recorded in any of the communities. The climbing fern, *Blechnum filiforme*, found predominantly on *Dysoxylum spectabile*, dominated all the forest plots. Other ferns that occurred in relatively high numbers included *B. novae-zelandiae, Microsorum pustulatum*, *M. scandens*, *Asplenium bulbiferum*, *A. flaccidum*, *A. oblongifolium* and *A. polyodon*.

No epiphytes or perching lilies were observed growing in the canopy trees, possibly due to the openness of the forest in the earlier days. The main forest areas were not fenced until 1961 (Wildlife Service, 1971) until then stock were able to utilise the forest. Another reason why epiphytes are not present could be summer droughts, which can impede the establishment and maintenance of epiphytes. In addition, older specimens of *Dysoxylum spectabile*, the main canopy tree in the forest remnants, seldom bear epiphytes (West, 1980). Plant species that preferred margins and gaps dominated open areas within the forest, for example, *Melicytus ramiflorus*, *Pittosporum tenuifolium* and *Brachyglottis repanda*,.

Ninety-five percent of the forest plots occurred on the south side of Maud Island. Topography of the forest plots was predominantly steep slopes. Several small creeks are located within the main forest.

Community 3: Forest/scrub

One hundred and eighteen species within 47 plots were classified into the forest/scrub community. The three main plant species that dominated the canopy in this community were *Pseudopanax arboreus, Melicytus ramiflorus and Brachyglottis repanda* both are indicative of open, disturbed sites. *Weinmannia racemosa, Beilschmiedia tawa* and *Carpodetus serratus* were also found in the canopy but in lesser numbers. In the sub-canopy/shrub layer the early seral plants *Olearia rani* , *Kunzea ericoides* , *Ascarina lucida* , *Leptospermum scoparium* , *Melicytus ramiflorus, Hebe stricta* var. *stricta* and *Pseudopanax arboreus* were being replaced with the canopy trees *Pennantia corymbosa, Weinmannia racemosa* and *Dysoxylum spectabile.* Several large *Cyathea medullaris* were observed growing in the damper areas and gullies within this forest. Due to the openness of some of the sites, pasture grasses and several weed species, such as *Digitalis purpurea, Lotus pedunculata,* and *Trifolium* sp., were observed in the undergrowth. *Pteridium esculentum* occurred in all plots. Due to over shading of the canopy trees *P.* esculentum was dying out and there was little re-growth. Under the *P.esculentum* there were numerous *Pseudopanax arboreus, Rhopalostylis sapida* and *Dysoxylum spectabile* seedlings. The common fern *Blechnum novae-zelandiae* dominated the fern layer. Other ferns present were *Asplenium flaccidum* on large trees, *A. bulbiferum* s.s. in the shadier, damper areas, and the coastal fern *Polystichum richardii*. The fern ally *Lycopodium volubile* was observed climbing over trees and shrubs in open areas.

Eighty percent of the forest/scrub plots were on the south side of the island. These included areas beside the main bush and an area near the fort which had been fenced off in late 1971 to early 1972 (Wildlife Service, 1971 & 1972). Along the edge of this fence line the exotic tree *Chamaecytisus palmensis* had been planted as a food source for wood pigeons (pers. comm., Bell 2001). The tree lucerne plants were very large and often had a lot of native tree seedlings under them.

Community 4: Coastal scrub

Ninety-three species in 34 plots were classified into the coastal scrub community. Predominant plant species included *Melicytus ramiflorus, Hebe stricta* var. *stricta, Brachyglottis repanda, Coprosma rhamnoides, Cyathea medullaris, Kunzea ericoides* and *Leptospermum scoparium*. The forest canopy trees *Beilschmiedia tawa, Carpodetus serratus, Pennantia corymbosa* and *Weinmannia racemosa* were dominant in tiers four (5-2meteres) and three (12- 5 meters). The dominant fern was *Blechnum novae-zelandiae*. Other ferns and fern allies included *Microsorum pustulatum, Asplenium bulbiferum* s.s., *Polystichum richardii, A. oblongifolium, A. flaccidum*, and *Lycopodium volubile*. Along the coastal cliffs and faces the coastal plants *Phormium cookianum, Coprosma repens* and *Ozothamnus leptophylla* dominated. These plant species will all tolerate exposed salty conditions (Ogle, 1987).

Ninety percent of all the plots had *P.esculentum* growing within them, probably due to the openness of many of the sites. *P.esculentum* provided shelter for many exotic weeds (25% of all plant species) and copious *Pseudopanax arboreus* seedlings. *Rubus cissoides* was found growing in these open coastal forest sites.

Community 5: Lowland scrub

Seventy-five species in 15 plots were classified into the lowland scrub community. On the peninsula isthmus, *Leptospermum scoparium* dominated the vegetation with the early successional shrubs *Hebe stricta* var. *stricta, Ozothamnus leptophylla, Coprosma robusta, Erica lusitanica, Olearia paniculata* and *Coprosma rhamnoides* in the understorey. On the exposed coastal faces, *Phormium cookianum* and *Arthropodium cirratum* dominated the vegetation. The predominant vegetation in other areas included *Leptospermum scoparium, Melicytus ramiflorus* and *Pseudopanax arboreus*. Other shrubs recorded within this community were the coastal shrubs *Dodonaea viscosa, Cyathodes juniperina, Griselinia littoralis* , the lowland forest tree *Myrsine australis* ,the short-lived herbaceous *Solanum aviculare* and the tree ferns *Cyathea medullaris* and *Cyathea dealbata* (Cockayne, 1967; Allan, 1982; Wardle, 1991). The forest canopy trees *Weinmannia racemosa, Pennantia corymbosa, Carpodetus serratus* and *Dysoxylum spectabile* occurred in very small numbers and predominantly as seedlings. The average height of the trees in this community was 2.5 metres. Due to the openness of many of the sites weeds and grasses accounted for 45% of the vegetation and *P.esculentum* was observed growing in 95% of the sites. In this community *P.esculentum* was dense in places and was vigorously re-growing and in places possibly inhibiting regeneration. In other communities on Maud Island *P.esculentum* appeared to be facilitating regeneration. This could be due to less moisture on this side of the island and cooler growing conditions. Only ferns that could tolerate open areas were observed in this community; they included *Asplenium bulbiferum* s.s., *A. oblongifolium, Blechnum novae-zelandiae* and the fern ally *Lycopodium volubile.* Plots were located predominantly on the peninsula and in areas on the south side of the island that were released from grazing in the late 1970s to early 1980s (N.Z.W.S, 1971, 1972 & 1985).

Community 6: Shrubland

Ninety-five species in 20 plots were classified into the shrubland community. The canopy within these plots was sparse and very open. Large *Chamaecytisus palmensis* were observed growing in many of the plots. Underneath the *C. palmensis* numerous seedlings of many of the tree species on Maud Island were observed, arising from seed deposited there from the droppings of the wood pigeons feeding on the trees. Other tree species noted in high numbers in this community included *Pseudopanax arboreus, Melicytus ramiflorus, Hebe stricta* var. *stricta, Ozothamnus leptophylla, Leptospermum scoparium, Coprosma rhamnoides, C. robusta, Erica lusitanica* and *Kunzea ericoides*, all early successional plants. In addition, the plots included *Pittosporum tenuifolium, Brachyglottis repanda, Dodonaea viscosa, Myrsine australis, C. propinqua* and *Teline monspessulana* a woody weed species that colonizes open disturbed ground. Seedlings of *Beilschmiedia tawa, Knightia excelsa* and *Weinmannia racemosa* were the only forest canopy species seen growing in these plots. Weeds and pasture grasses, e.g., *Dactylis glomerata, Holcus lanatus*, *Bromus hordeaceus, Taraxacum officinale, Lotus pedunculatus* and the native *Microlaena stipoides* dominated in open areas. In some areas the grasses were being shaded by the trees and were dying out. *P.esculentum* also grew in the open areas (95% of all the plots) and appeared to be spreading.

The plots were predominately on the north-east side of the island. In addition, on this side of the island there are several enclosures built in the 1970s for kakapo. Inside the enclosures 400 autumn fruiting trees and shrubs were planted as supplementary feeding for the kakapo; these included *Eucalyptus leucoxylon, Vitis* sp., *Malus* sp., *Pyrus* sp.,*Ribes grossularia* , *Rubus* sp. and *Helianthus* sp. (N.Z.W.S, 1985). Most of these plant species have since died out or been cut down and the enclosures are reverting to native scrub.

Community 7: Shrubland/ pasture

Seventy plant species in 12 plots were classified into the shrubland/ pasture community. The plots occurred near the houses on the southern side of the island and on the north-eastern side of the island. Vegetation within this community was predominately pasture interspersed with small patches of scrub. The scrub included the early successional plants of *Pseudopanax arboreus, Melicytus ramiflorus, Ozothamnus leptophylla, Leptospermum scoparium, Coprosma robusta, Erica lusitanica, Kunzea ericoides* and *Coprosma rhamnoides*. The canopy trees, *Pennantia corymbosa, Carpodetus serratus* and *Elaeocarpus dentatus* were observed only as large solitary trees in the paddocks no regeneration was occurring because sheep still graze these pastures.

The pasture was a mixture of weeds and grasses, e.g., *Dactylis glomerata, Lolium, Holcus lanatus* and the native *Rytidosperma racemosum*. The native *Acaena anserinifolia* occurred in large numbers in all the plots, this high density is possibly due to the seeds being spread by sheep. The nitrogen fixing *Lotus pedunculatus* also occurred in high numbers. Thirteen kilos of *L. pedunculatas* seeds was sown on the eastern side of the island in 1975, by the Wildlife Service, as supplementary food for kakapo (NZWS, 1972). Other weeds included *Digitalis purpurea, Taraxacum officinale, Oxalis rubens, Cerastium glomeratum, Cirsium vulgare, Geranium dissectum, Trifolium* sp., *Vicia sativa, Rumex acetosella, Plantago lanceolata* and the uncommon *Linum trigynum*. The high level of weeds may be due to their introduction with the pasture grass seeds when paddocks were ploughed and re-sown in the early farming days. *P.esculentum* occurred in high numbers but, due to trampling, it was struggling to survive. Several damp areas were observed in this community and the native rushes *Juncus gregiflorus* and *J. pallidus* and the introduced *Hydrocotyle* sp. grew there as well as the pasture grasses.

Community 8: Pasture

Twenty-four species in nine plots were classified into the pasture community. This community had the lowest number of plant species apart from the pine plantation. Community 8 was predominantly pasture grass, e.g., *Dactylis glomerata, Holcus lanatus, Rytidosperma racemosum* and *Poa annua*. Due to the dense grass sward there were very few weeds. The weeds that did occur included *Trifolium* sp., *Lotus pedunculata, Taraxacum officinale* and *Hydrocotyle* sp. Some seedlings of *Chamaecytisus palmensis, Pseudopanax arboreus, P.esculentum* and several large shrubs of *Ozothamnus heterophylla* were observed growing in the plots. These plots occurred primarily on the eastern side of the island, had the lowest slope, and were still used for grazing.

3.1.4 *Detrended Correspondence Analysis (DCA): using ordination to describe the gradient structure in plant community composition*

Detrended correspondence analysis (DCA) of the reduced dataset of 98 species in 156 plots resulted in a gradient length of greater than four (Table 3.3, Figure 3.2). This high gradient length reflects the high turnover in species composition in the dataset and indicates that detrending was necessary. Detrending removes the 'arch effect' seen in other ordinations where turnover in species composition across the plots is high (ter Braak and Šmilauer 2002). The high gradient length in the DCA indicates high turnover in species composition in the dataset. This is also illustrated by the wide spread of species and plots across the first two DCA axes (Figure 3.2). Sites with similar species composition are positioned closer together, and species that occur in similar sets of sites are positioned closer together on the ordination diagram. The high eigenvalue for axis one shows that there was strong gradient structure in the dataset (Table 3.3).

3.1.5 *Canonical Correspondence Analysis (CCA): using ordination to relate the gradient structure in plant community composition to environmental variables*

To explain the strong gradient structure quantified by the DCA, I used canonical correspondence analysis (CCA) to relate variation in species composition of plots to the following environmental variables: aspect, slope, presence of moss, percent cover of litter, percent cover of soil, log-transformed percent cover of rock and square-root-transformed altitude (Table 3.4, Figure 3.3). Ordination uses the weighted average for each species to place the species in a biplot closest to the environmental factors that have the most influence on how it is distributed among the samples (ter Braak, 1986). This CCA was performed on the reduced dataset of 98 species in 156 plots, and resulted in species and sites with similar weighted averages to be interpretively placed along CCA axes that were driven by the most important environmental gradients (Figure 3.3). The positions of the environmental vectors are determined by the eigenvalue of the environmental variable they represent (Table 3.4). The closer that a species is placed to the environmental factor vector, the more strongly its distribution among sites is influenced by this factor. The longer the vector, the more influential the environmental variable it represents is on the ordination. The total inertia (variance) of the eigenvalues was relatively high, at 5.108. This indicates that there was a large amount of variation in species abundances in the dataset.

From the CCA analysis, species found in the Forest Community (steeper slopes and less disturbed sites), such as *Dysoxylum spectabile*, *Ripogonum scandens* and *Blechnum filiforme*, were positioned on the left of CCA axis 1. Species that preferred more disturbed sites, mainly the Grassland Communities, such as *Dactylis glomerata, Holcus lanatus, Rytidosperma racemosum* and *Acaena novae-zelandiae* were positioned on the right of CCA axis 1. The early colonizing species, such as *Pseudopanax arboreus, Kunzea ericoides, Leptospermum scoparium, Hebe stricta* var. *stricta* and *Melicytus ramiflorus*, were located nearer the middle of CCA axis 1. Therefore, I can interpret CCA axis 1 to be a historical disturbance gradient. Plots in areas that have had little disturbance are seen to occur on the left of CCA axis 1 and those communities that are still utilized for farming occur on the right of CCA axis 1.

The CCA also showed that altitude was the most important measured environmental factor for explaining variation in species composition along axis 2; the vector for altitude was the longest and was close to this axis. Aspect and litter also influenced plant species composition. Slope and percent cover in plots of soil were of still lesser importance. Percent rock and percent moss had only a very small influence on species composition (Kent & Cocker, 1992; Belland & Vitt, 1995). I can interpret CCA axis 2 to be an environmental gradient in moisture. Plant species that preferred drier conditions such as *Phormium cookianum* and *Erica lusitanica* and were positioned at the top of axis two. Two *Juncus* species, plants that prefer wetter conditions were positioned lower on axis two.

3.2 Succession of Plant Communities on Maud Island 1980-2001

3.2.1 *Comparisons of vegetation maps from 1980, 1990 and 2001*

While this study has used more quantitative methods than the previous two studies there is sufficient information too compare and look at general patterns over the last twenty years. The first comprehensive study of the vegetation of Maud Island was conducted by Colin Ogle in 1980-1981. He classified the vegetation into 16 different communities (Figure 3.4). In 1991, J. Dix also identified and mapped 16 different communities (Figure 3.5). I used the eight communities identified using TWINSPAN to create a vegetation map of Maud Island for 2001 (Figure 3.6). Taking my analysis to sixteen communities was not possible using TWINSPAN.

Overlaying the classification of plots from this study onto Ogle's vegetation map from 1980 gives us a semi-quantitative perspective on the path of succession on Maud Island (Table 3.5, Figure 3.7). The most obvious result from these comparisons is that the 1980 communities of bracken with scattered scrub are now predominantly forest scrub. In the main, areas with bracken/grass/shrubs have become scrub community, the young secondary forest has become forest, and the areas of grass/bracken are now pasture. There has been a general trend from communities of low stature, dominated by grasses and shrubs, towards forest (Figure 3.6). While it seems unlikely that the young secondary forest has become forest this could be due to my interpretation of what Ogle classified this community as. The small number of plots that appear to have reverted to grassland from forest and shrubland are due to the slight error in the GIS when overlaying the vegetation map from 2001 onto Ogle's 1980 map.

Visual comparison of the 1980 and 2001 maps with Dix's 1990 map also helps build the story of vegetation change. On the peninsula, including the isthmus, Ogle classified five plant communities. These communities were: (1) *P.esculentum* fernland with scattered shrubs less than 20%, mainly *Erica lusitanica, Leptospermum scoparium* and *Hebe stricta* var. *stricta*; (2) grasses, shrubs and *Pteridium esculentum*; (3) grass with scattered shrubs less than 20% mainly *Ozothamnus leptophylla* and *Pteridium esculentum;* (4) fernland with almost no grass or shrubs; (5) grassland. Dix classified the peninsula in a similar manner, the isthmus being predominantly tutu scrub and the main area of the peninsula being shrub/bracken and fern communities with a slightly smaller area of pasture. This study identified only three communities on the peninsula. The isthmus and Harter Point had advanced to lowland scrub with *Leptospermum scoparium* dominating the canopy with an understory of early successional scrub, e.g., *Olearia paniculata*, *Coprosma* sp. and *Pseudopanax arboreus*. On the main area of the peninsula the bracken/fernland had changed to coastal scrub with a small central area of pasture (which is maintained by D.O.C. workers using scrub bars) that was utilized by takahe and burrowing seabirds.

The mature forest in 1981 was flanked by *P.esculentum* scrub with scattered shrubs, predominantly *Hebe stricta* var. *stricta, Pteridium esculentum, Ozothomanus leptophylla, Erica lusitanica*, *Leptospermum scoparium,* and small patches of secondary forest with *Fuchsia excorticata, Pseudopanax arboreus, Dysoxylum spectabile, Carpodetus serratus* and *Pennantia corymbosa.* In 1990, Dix found that the secondary forest (forest/scrub) had spread out from the mature forest, particularly in the Boat Bay area. She found the same species associations as Ogle had and also included *Macropiper excelsum.* Dix also noted that one of the major changes within the mature forest was that the cover of seedlings, including *Pennantia corymbosa, Alectryon excelus* and *Rhopalostylis sapida,* had increased conspicuously over the previous few years. In 2001, I found the secondary forest was significantly larger in area, there was a greater diversity of plants and there was high numbers of seedlings and saplings of all forest canopy trees including *Dysoxylum spectabile.*

Within the main forest block, regeneration of all major canopy species is occurring, with high numbers of seedlings of *Dysoxylum spectabile, Carpodetus serrata* and *Beilschmiedia tawa* in the undergrowth. This was also noted by Dix. In this area, Ogle found an absence of epiphytic orchids but he found a few perching lilies and filmy ferns. He had thought that as conditions improved over time, these species would return; unfortunately they have not. The absence of filmy ferns and perching lilies is not a concern because they should return over time, as the forest becomes denser and damper with less drafts.

Both Ogle and Dix noted that the areas beyond the *P.esculentum* scrub and secondary forest were predominantly grass, *Pteridium esculentum*, with scattered patches of mixed scrub *Hebe stricta* var. *stricta, Ozothamnus leptophylla, Pseudopanax arboreus* and *Leptospermum scoparium*) and *Coriaria arborea*scrub. By 2001, these areas were a mosaic of coastal scrub, forest scrub and lowland scrub.

The areas categorized in 1981 and 1990 as eroded faces and cliffs and outcrops with sparse herbs and ferns, supported a denser canopy of shrubs in 2001. The slip in Cable Bay, however, had little vegetation due to it slipping again in 2000.

Major changes have occurred on the western side of the island. In 1980 Ogle classified this side of the island as predominantly grass with scattered shrubs (less than 20%, mainly *Ozothamnus leptophylla*) and areas of *P.esculentum* with no shrubs. Dix reported similar results, but with more grazed areas and *Erica lusitanica* as the dominant shrub species. In 2000, I found the pasture had reduced in size and shrubland had increased with *Erica lusitanica* still a major component. I also found large numbers of seedlings of the colonizing species, *Pseudopanax arboreus, Melicytus ramiflorus* and *Kunzea ericoides* under the *P. esculentum* and *Erica lusitanica.* The large *Streblus banksii* found on this side of the island has also improved in health (Figure 3.8) and many seedlings were found in scrub areas adjacent to the tree.

At Southwood Point, Ogle classified the area as grass with scattered shrubs predominantly *Ozothomnus leptophylla,* and with an area of short-grassed grassland. By 1990 this community was dominated by *P.esculentum* fernland with almost no grass or shrubs, *P.esculentum* fernland with shrubs and un-grazed grassland. In 2001, scrub dominated with a distinct pattern: on the west side of the point coastal scrub dominated and the east side was dominated by lowland scrub.

In 1981, Ogle classified the Fort Point as predominantly grass, shrubs and *Pteridium esculentum;* Dix noted similar composition in 1990 with two large areas of grazed pasture. In 2001, lowland shrub, coastal scrub and shrubland dominated.

Two previously unrecorded plant species for the island were found in this study. One *Dacrydium cupressinum* approximately 1.5 metres tall was found in the scrub just above Boat Bay Road on a transect line. It is unsure how the *Dacrydium cupressinum* arrived; suggestions include someone planting it, although there are no records of this, or a seed in the gut of a bird from a local source or in the gut of kakapo transferred from Codfish Island. Nick Head found three *Plagianthus divaricatus* (saltmarsh ribbonwood) in Boat Bay near the isthmus.

Ogle noted that several plant species were confined to the banks of the bulldozed tracks and could be regarded as recent re-introductions. Ogle found one *Metrosideros umbellata* (southern rata) in Boat Bay on the track near the forest, in 2001. The seeds for this plant were possibly blown over from nearby mainland forest. This study also found *Metrosideros umbellata* in this area and in the forest scrub community. Ogle also found only two instances of *Ascarina lucida* (hutu) on the Ring Road by Boat Bay, in 2001, plants up to four metres in height and many seedlings and saplings were found growing in the forest scrub on both sides of the Ring Road.

In 1980, Ogle did not find any plants of *Ulex europaeus* or *Clematis vitalba* (old man's beard); however, I found two areas of *Ulex europaeus* near the summit and several vines of *Clematis vitalba* in various locations. A weed survey map (Appendix 4) compiled by weed personnel from Havelock Department of Conservation (D.O.C.) staff in 1999 also shows several areas of these weeds. At present both of these weeds are controlled by D.O.C. In addition, several species planted by the Wildlife Service as a supplementary food for introduced birds have been removed since Ogle's plant survey, including *Crataegus monogyna* , *Tradescantia fluminensis* ,*Rubus fruticosus*, *Cornus capitata* , and *Passiflora mollissima*.

3.2.2 *Comparisons of aerial photographs from 1963, 1993 and 2000*

The vegetation on Maud Island is reverting from grassland/small stature scrub to treeland/larger scrub this is obvious when comparing aerial photos of Maud Island from 1963 (Appendix 6), 1993 (Appendix 7) and 2000 (Appendix 8) .When comparing the 1993 photo with the 2000 photo there is a track at the right of the bottom house in the grassland in 1993 and by 2000 this has been covered over by scrub. However, the greatest differences can be seen when comparing the 1963 photo with the 2000 photo; in 1963, there are no pine plantations, the main bush is clearly visible and the island appears barren in many places.

3.2.3 *Comparisons of photo-points 1990 and 2001*

In 1990, Dix set up 14 separate photo-point locations, from which 26 parts of the island were photographed. These were re-visited in April 2001. In some cases it was difficult to relocate the photo-points due to changes in the vegetation. Photos were taken in each area where possible and a G.P.S. point was recorded (Appendix 9). It must be noted that not all areas have a G.P.S. point due to the G.P.S. being unable to pick up satellites.

Repeat photos (photo-points) are useful to show vegetation (particularly woody species) changes over time. The photo-points from Dix's and this study are an excellent record to show how the vegetation on Maud Island has changed over time.

In this study I have put my interpretations of the vegetation changes observed when comparing the photos, in the figure captions. The photo-points clearly show that the vegetation on Maud Island is changing from short stature shrubland/bracken and grassland to taller shrub and young secondary forest (Figures 3.9 – 3.32). They show that as farming practices such as grazing and fencing are removed from an area the vegetation changes from short stature grassland to scrub and in time coastal forest. The areas that are prone to slipping show clearly in the photos and regeneration of the vegetation in these areas can be seen plainly.

Table 3.1: The eight major plant communities on Maud Island identified using Two-Way Indicator Species Analysis (TWINSPAN) of the 177 species present in 158 plots.

Community	Number of plots	Dominant species	Description	% indigenous species	% exotic species	Species richness
C1	2	*Pinus radiata*	Pine plantation	0	100	1
C2	19	*Macropiper excelsum – Dysoxylum spectabile - Rhopalostylis sapida*	Forest	80	20	96
C3	47	*Pseudopanax arboreus - Brachyglottis repanda - Pteridium esculentum*	Forest/scrub	77	33	118
C4	34	*Pseudopanax arboreus - Hebe stricta* var. *stricta - Pteridium esculentum*	Coastal scrub	60	40	93
C5	15	*Hebe stricta* var. *stricta - Leptospernum scoparium - Pteridium esculentum*	Lowland scrub	70	30	75
C6	20	*Pseudopanax arboreus - Pteridium esculentum* - pasture grasses [1]	Shrubland	70	30	95
C7	12	*Dactylis glomerata* - exotic weeds [2] - *Pteridium esculentum*	Shrubland/ pasture	69	31	70
C8	9	*Dactylis glomerata - Holcus lanatus*	Pasture	26	74	24

[1] *Holcus lanatus, Dactylis glomerata, Rytidosperma racemosum.*

[2] *Trifolium* sp., *Geranium dissectum, Hydrocotyle* sp., *Oxalis rubens, Rumex acetosella, Plantago lanceolata, Cirsium vulgare, Vicia sativa.*

Table 3.2: Summary of all environmental data (means) for all eight communities.

	Community							
Environmental variable	C1: Pine plantation	C2: Forest	C3: Forest/scrub	C4: Coastal scrub	C5: Lowland scrub	C6: Shrubland	C7: Shrubland/pasture	C8: Pasture
% Litter	60	50	39	44	47	37	35	29
% Exposed Soil	5	23	18	17	17	11	11	12
% Rock	10	16	15	9	4	29	15	24
% Moss	0	9	7	6	0	8	3	4
% Vegetation Cover	90	65	66	69	73	69	77	72
Mean height (m)	12	9	3.5	2.5	1.5	1	.8	<0.5
Slope	45	48	37	37	42	38	36	29
Topography	Faces	Faces	Faces and Gullies	Faces and Ridges	Faces	Faces	Faces and Ridges	Faces

Table 3.3: Eigenvalues, gradient lengths, and percent variance of the first four axes of a detrended correspondence analysis (DCA) of 98 vascular plant species in 156 plots. The two plantation plots composed of only *Pinus radiata*, and species occurring in fewer than 2% of plots were excluded from this analysis.

Axes	DCA1	DCA2	DCA3	DCA4	Total inertia
Eigenvalues	0.535	0.204	0.163	0.120	5.108
Lengths of gradient	4.911	2.524	2.688	1.991	
Cumulative percentage variance	10.5	14.5	17.7	20.0	
Sum of all eigenvalues					5.108

Table 3.4: Eigenvalues, species-environment correlations, and percent variance of the first four axes of a canonical correspondence analysis (CCA) of 98 vascular plant species in 156 plots. Axes were constrained by correlations with the plot-level variables: aspect, slope, presence of moss, percent cover of litter, percent cover of soil, and log-transformed percent cover of rock. All axes were significant at $P<0.01$. The two plantation plots composed of only *Pinus radiata* and species occurring in less than 2% of plots were excluded from this analysis.

Axes	CCA1	CCA2	CCA3	CCA4	Total inertia
Eigenvalues	0.235	0.082	0.069	0.060	5.108
Species-environment correlations	0.703	0.714	0.642	0.676	
Cumulative percentage variance					
of species data	4.6	6.2	7.6	8.7	
of species-environment relation	43.1	58.1	70.8	81.8	
Sum of all eigenvalues					5.108
Sum of all canonical eigenvalues					0.545

Table 3.5: Number of plots classified in Colin Ogle's 16 plant communities in 1980 compared to their classification using the eight communities identified using TWINSPAN in this study. Ogle's communities are assigned a 2001 classification based on their 1980 description.

		Plant communities identified using the 2001 TWINSPAN arranged in a 'successional' sequence							
Communities from Ogle (1980)	Probable 2001 classification	C8 Pasture	C7 Shrubland/ pasture	C6 Shrubland	C5 Lowland scrub	C4 Coastal scrub	C3 Forest scrub	C2 Forest	C1 Pines
Tall ungrazed grassland	C8							2	
Grazed grassland/ few shrubs	C8		2	5					
Short grasses/ ferns	C8			1		1			
Grass/ bracken	C8	6	1	1		1		2	
Grass/ scattered scrub	C7		7	2		4	2		
Grass/ shrubs/ bracken	C7	1	2	5	6	18	6	1	
Bracken fernland	C7			1			2	2	
Bracken/ shrub/little grass	C6	1				6	7		
Bracken /scattered shrubs	C6			5		8	30	1	
Regenerating shrubland	C6			1					
Mixed scrub	C5					1			
Shrubs/ ferns/ herbs on cliff/ rock faces	C4						1		
Young secondary forest	C3							1	
Mature native forest	C2	1						9	
Pine	C1						2	1	2

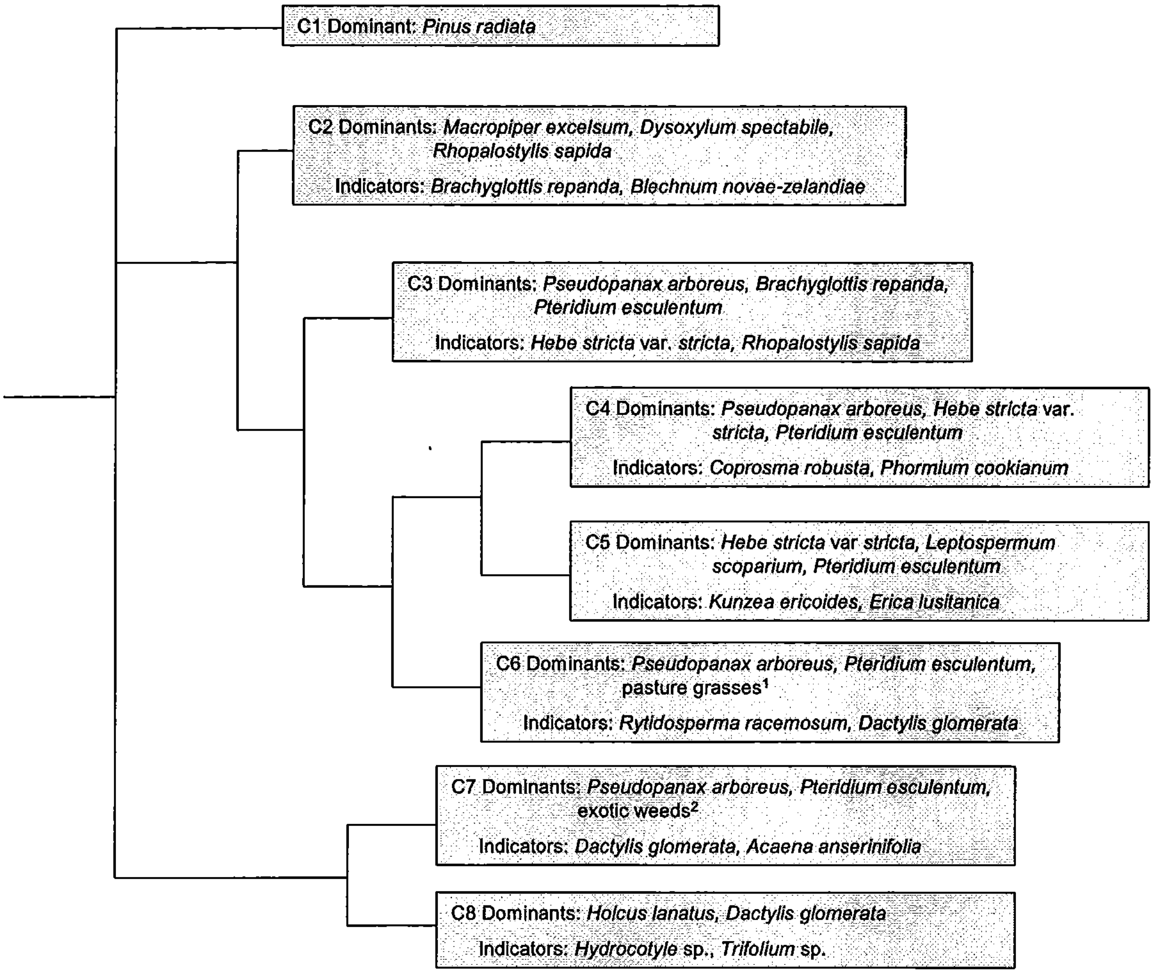


Figure 3.1: Dendrogram showing the relationships among the eight major plant communities on Maud Island, derived from Two-Way Indicator Species Analysis (TWINSPAN). Dominants = dominant species occurring within greater than 70% of plots within that community type. Indicators = indicator species identified by the TWINSPAN. [1] *Holcus lanatus, Dactylis glomerata, Rytidosperma racemosum.* [2] *Trifolium* sp., *Geranium dissectum, Hydrocotyle* sp., *Oxalis rubens, Rumex acetosella, Plantago lanceolata, Cirsium vulgare, Vicia sativa.*

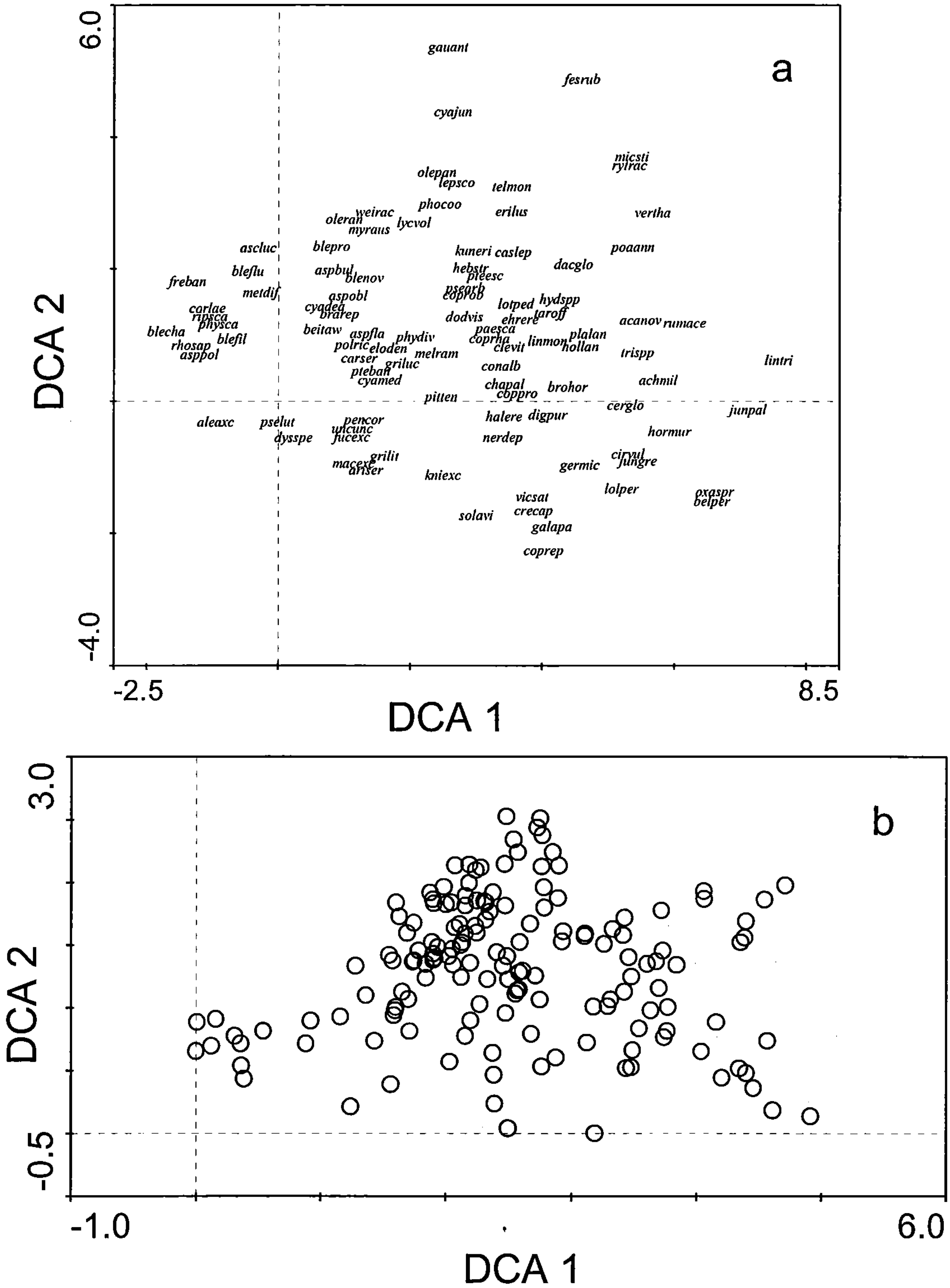


Figure 3.2: Ordination diagrams showing DCA axis 1 and axis 2 (a) species scores and (b) site scores for 98 species in 156 plots. Only species in greater than 2% of plots were included. The two plantation plots composed only of *Pinus radiata* and species occurring in less than 2% of plots were excluded from this analysis. See Appendix 5 for species abbreviations.

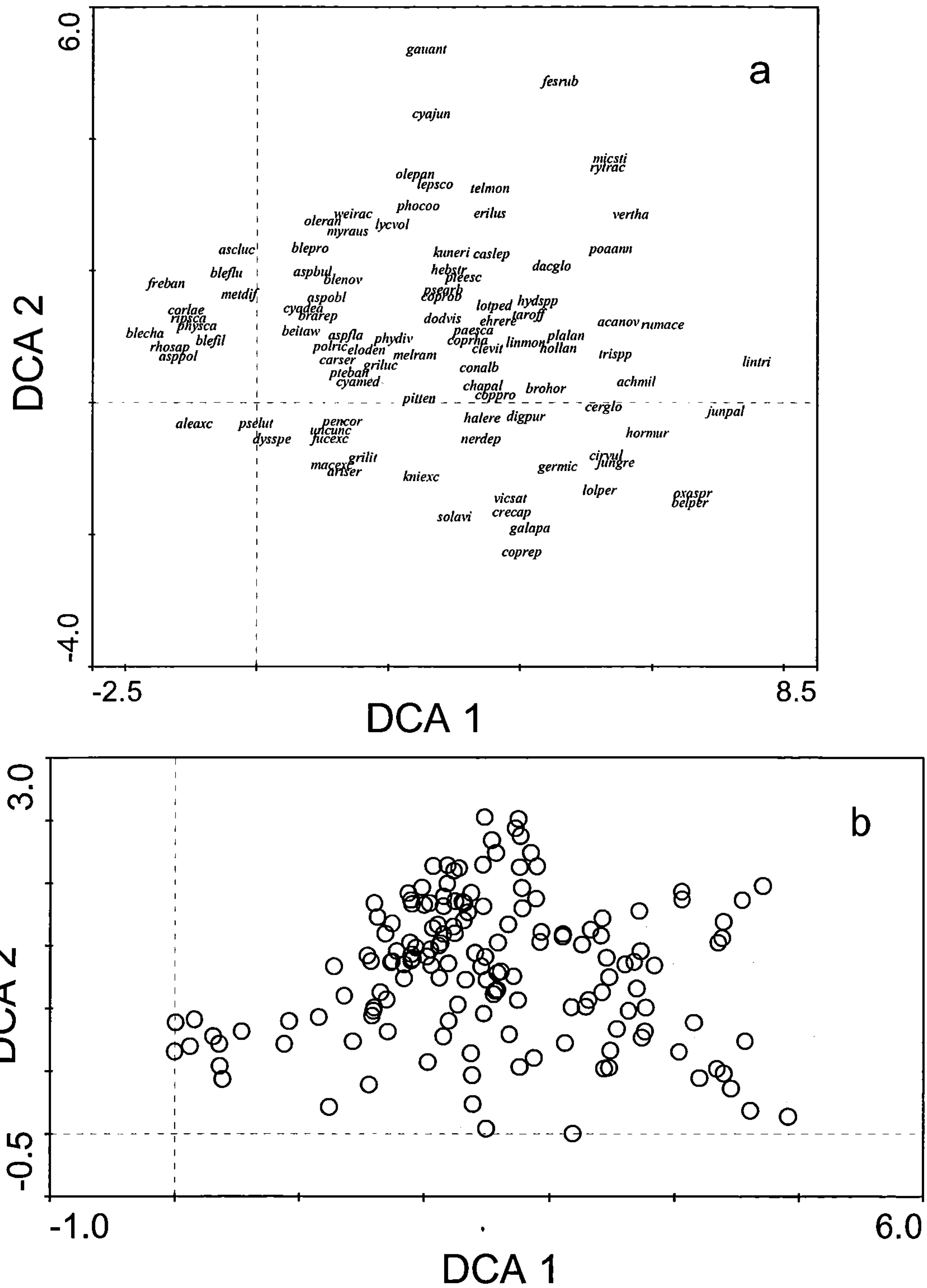


Figure 3.2: Ordination diagrams showing DCA axis 1 and axis 2 (a) species scores and (b) site scores for 98 species in 156 plots. Only species in greater than 2% of plots were included. The two plantation plots composed only of *Pinus radiata* and species occurring in less than 2% of plots were excluded from this analysis. See Appendix 5 for species abbreviations.

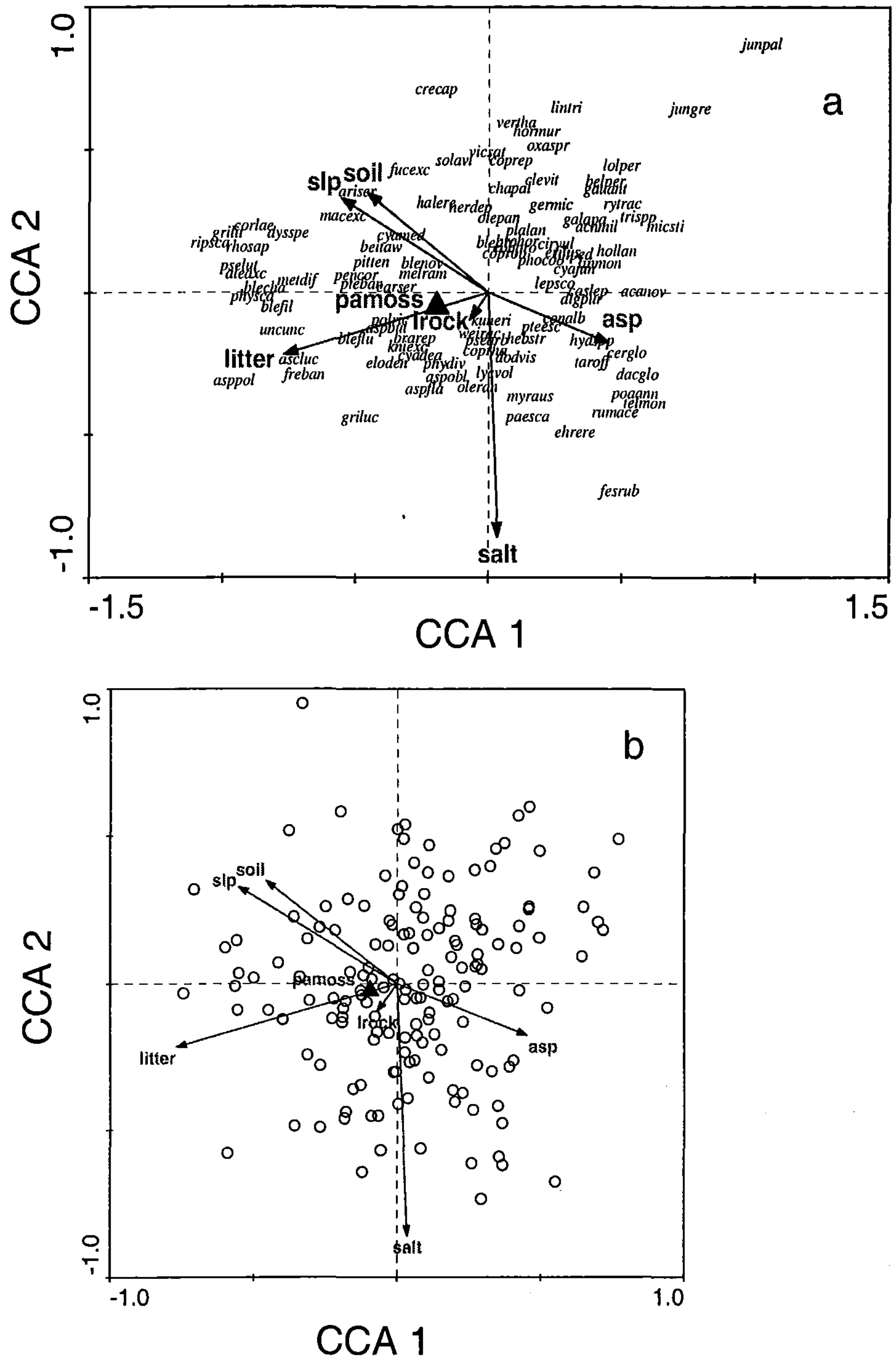


Figure 3.3: Ordination diagram showing CCA axis 1 and axis 2 (a) species scores and (b) site scores with environmental variable vectors for 98 species in 156 plots. The centroid of the categorical environmental variable presence of moss is represented by a triangle. Only species in greater than 2% of plots were included. The two plantation plots composed only of *Pinus radiata* were also excluded. See Appendix 5 for species abbreviations. (slp = slope, lrock = log-transformed percent cover of rock, salt = square-root-transformed altitude, asp = aspect, litter = percent cover of litter, pamoss = presence of moss, soil = percent cover of soil)

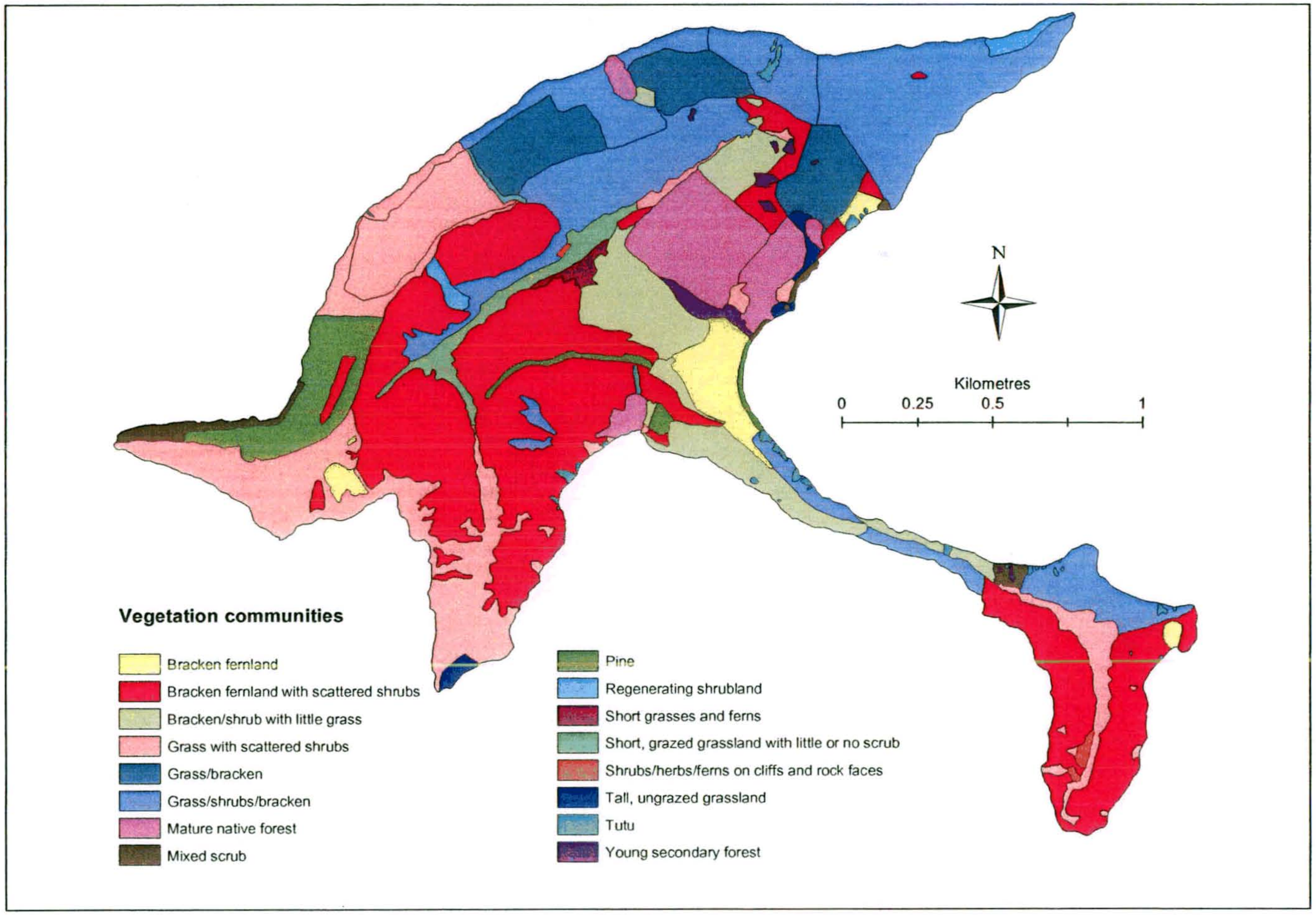


Figure 3.4: Vegetation Map Maud Island (recreated by digitizing and mapping the original image of Ogle 1980).

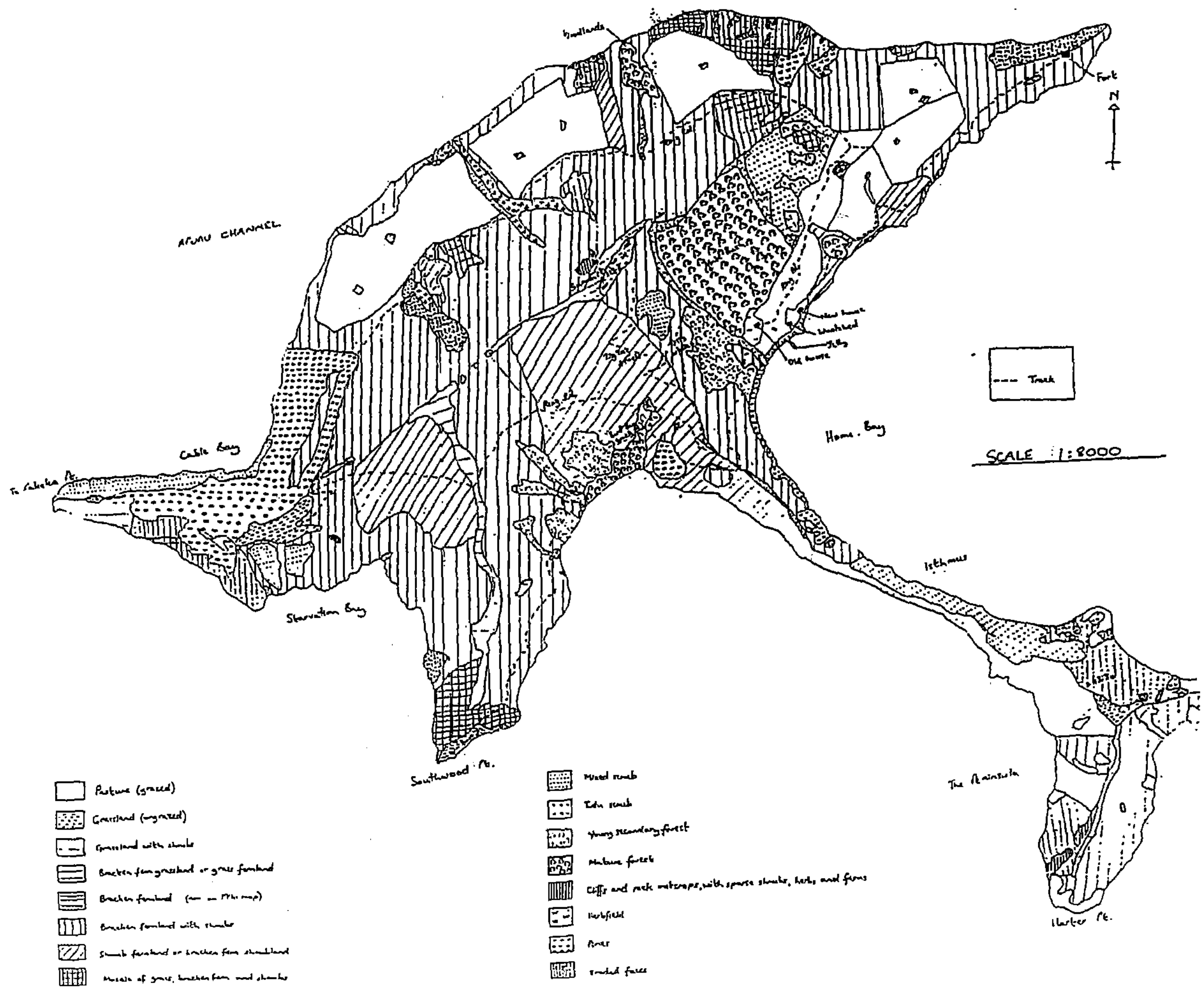


Figure 3.5: Vegetation map for Maud Island (Dix 1990).

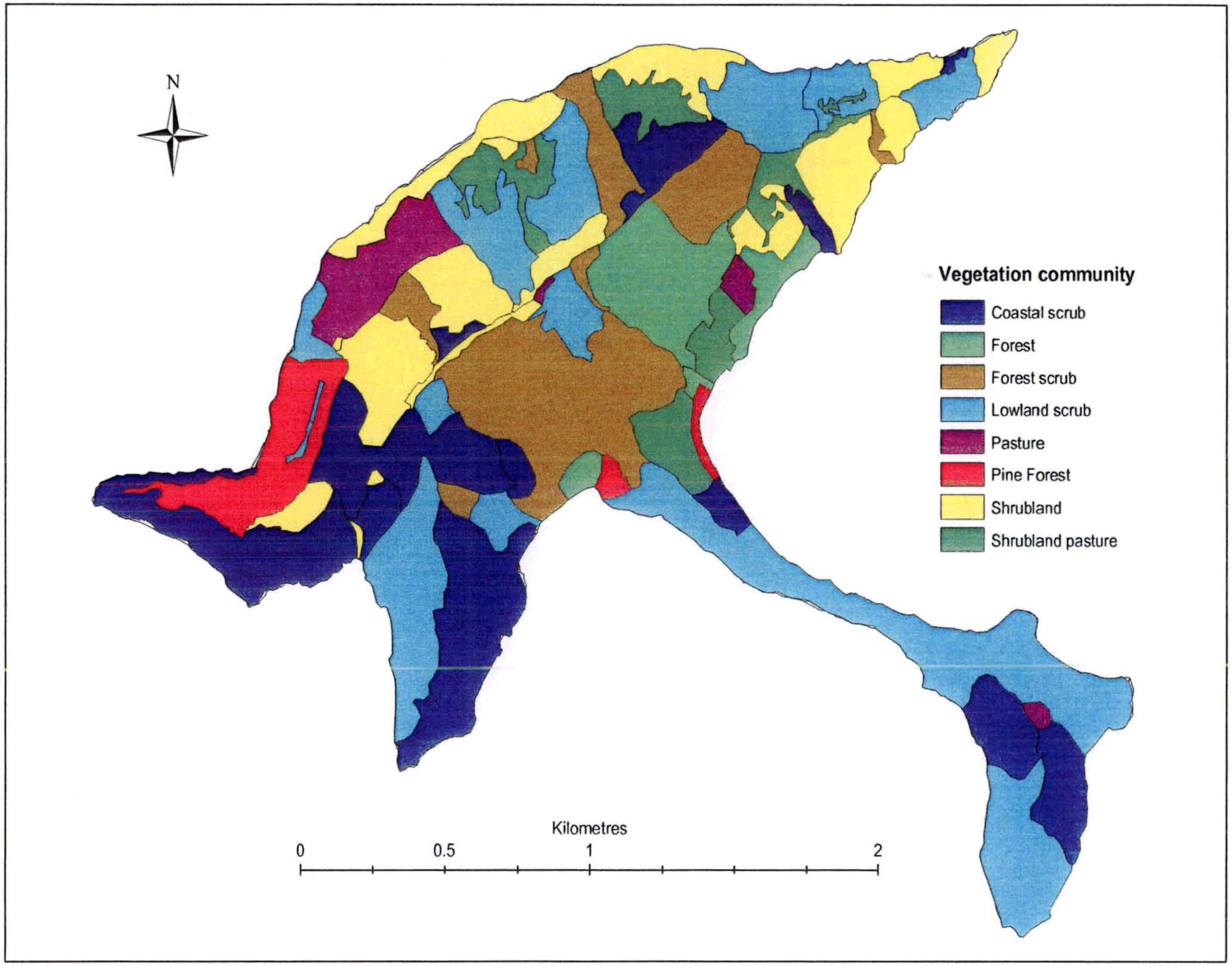


Figure 3.6: Vegetation map, Maud Island, created from sampling conducted in this study (2001).

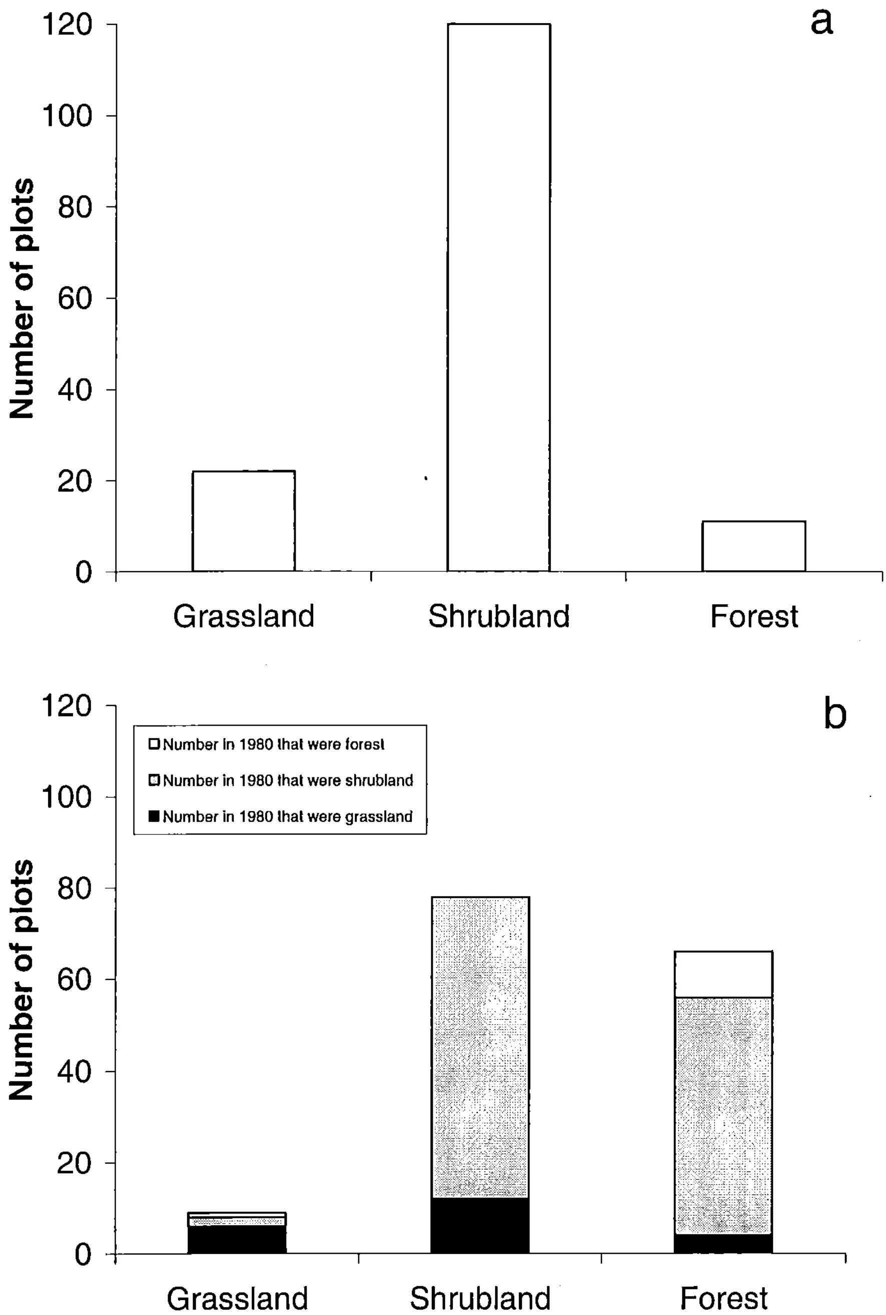


Figure 3.7: Barplots showing the number of plots in three broad community types (grassland, shrubland and forest) in (a) 1980 and (b) 2001. Bars in 2001 are divided up to show the number of plots that were classified in the three community types in 1980.

Figure 3.8. Comparisons of *Streblus banksii* in Milk Tree Bay, Maud Island. The picture was not taken in the same place due to the changes in the vegetation making access to the 1979 photopoint impossible in 2001 (E. S Kennedy, 1979; L. Sheldon-Sayer, 2001).

Figure 3.9: Photograph taken from photopoint A1 in 1990. A 2001 photo was not retaken as it was too difficult to get to the original photo-point site.

(a)

(b)

Figure 3.10: Photographs taken from photopoint A2 in (a) 1990 and (b) 2001. Both photos show areas of open grasslands and rock. In the 2001 photo these areas are less defined.

(a)

(b)

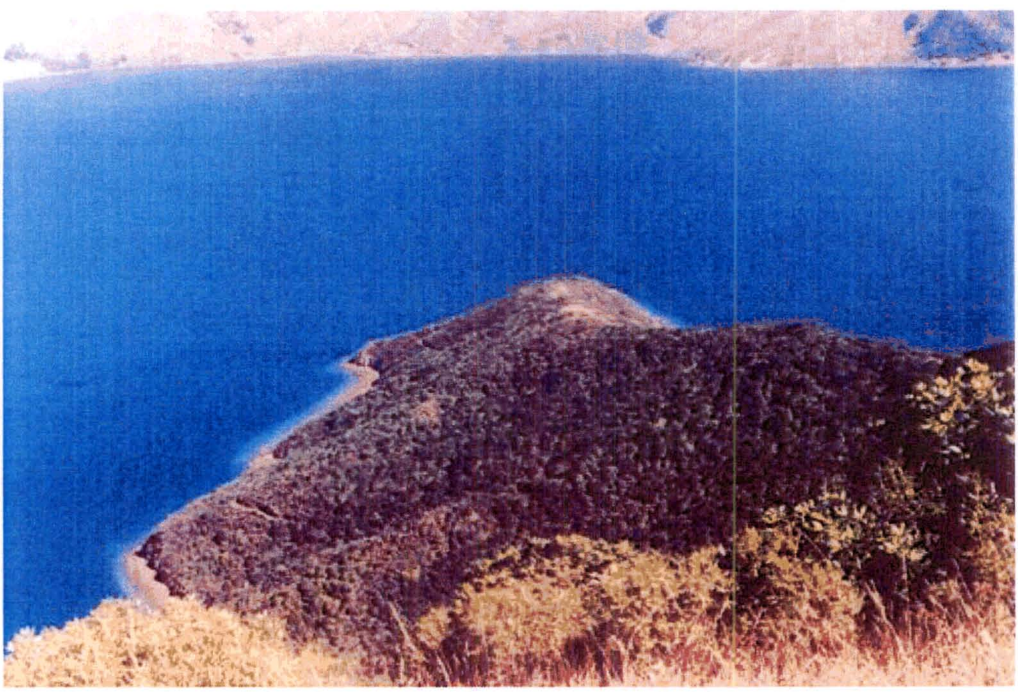


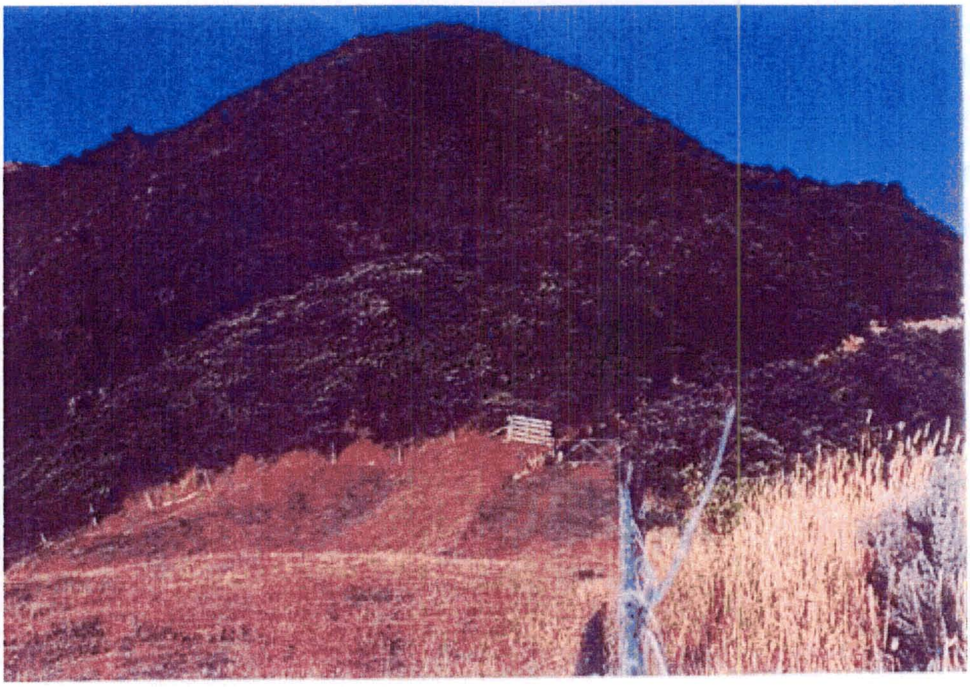
Figure 3.11: Photographs taken from photopoint A3 in (a) 1990 and (b) 2001. This photo -point looks down on Southwood Point. In 1990, areas of grassland are visible amongst the mixed scrub and on the ridge top. In 2001, grasslands are not visible in the scrub and the exposed areas on the ridge top areas have reduced significantly.

(a)

(b)

Figure 3.12: Photographs taken from photopoint B in (a) 1990 and (b) 2001. Herb field below summit. In 1990, the herb field is dominated by exotic grasses and weeds. In 2001, *P.esculentum* is clearly visible with pasture grasses.

(a)



(b)

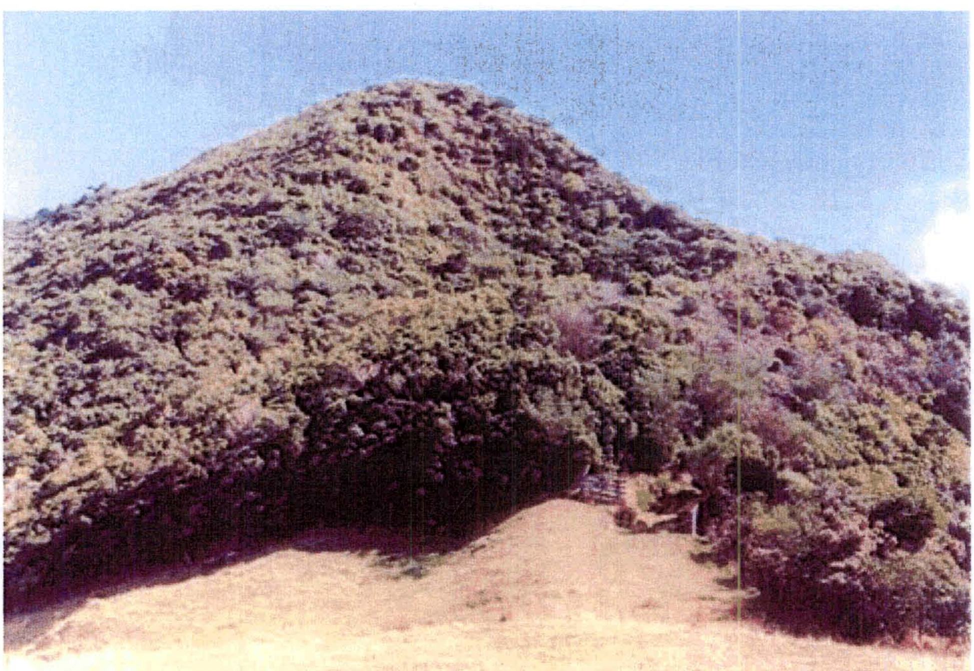


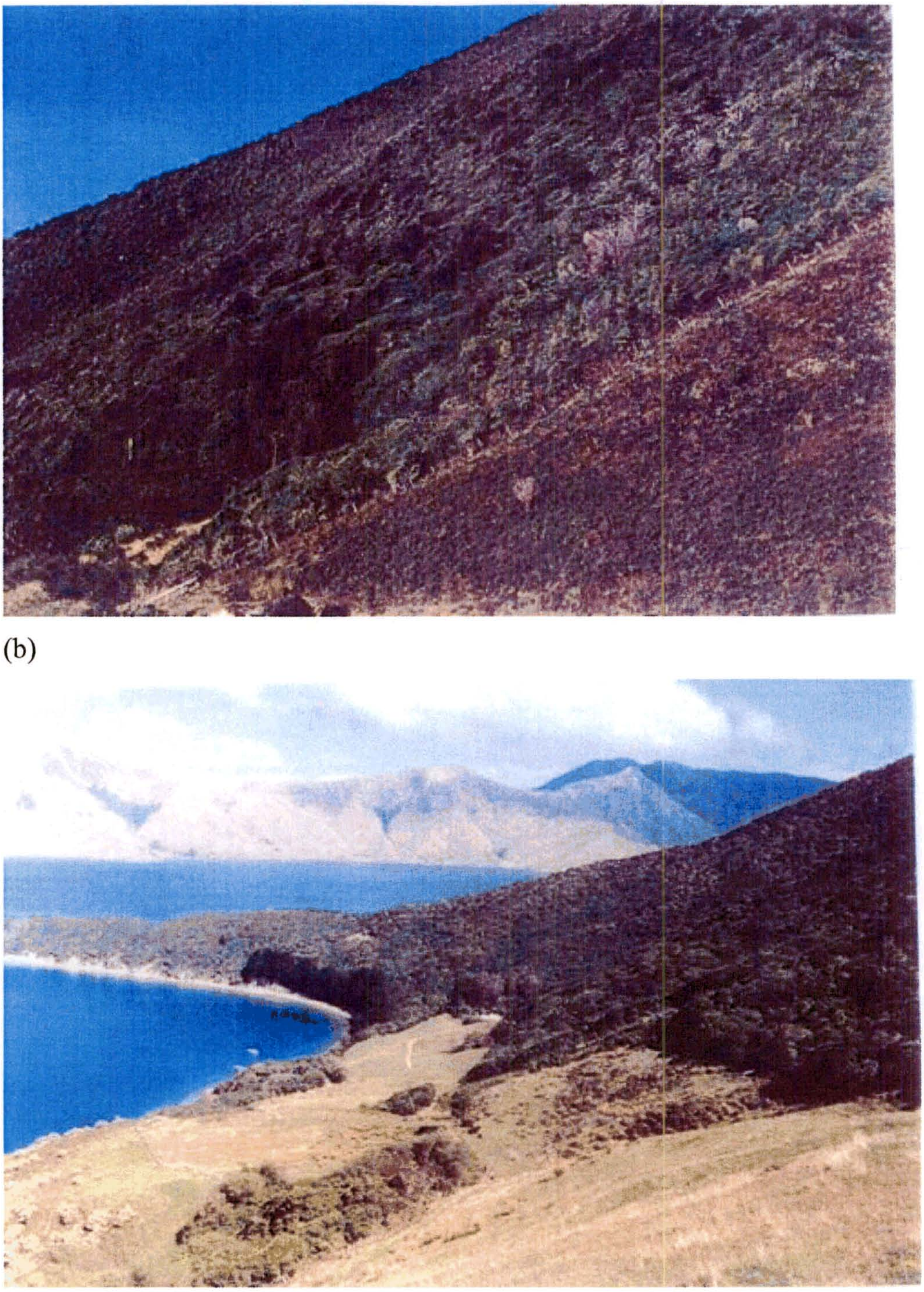
Figure 3.13: Photographs taken from photopoint C in (a) 1990 and (b) 2001. On ridge by wind tower base. In 1990, the fence lines are clearly visible, and exotic grasses, *Ozothamnus leptophylla* and *P.esculentum* dominate the right-hand side of the photo. Sparse scrub, with patches of grass, dominates the hill. In 2001, scrub dominates all areas. Note *Chamaecytisus palmensis* trees in scrub to the right of the gate.

(a)

(b)

Figure 3.14: Photographs taken from photopoint D in (a) 1990 and (b) 2001. This photo looks at the main forest from the paddocks. In the 1990 photo, the main forest is clearly seen as a dark strip in the centre of the photo. In 2001, the forest edges have blurred as the surrounding scrub has matured to secondary forest.

(a)



(b)

Figure 3.15: Photographs taken from photopoint A2 in (a) 1990 and (b) 2001. In the 1990 photo, the foreground is dominated by *Pteridium esculentum*, grasses and a few shrubs. In 2001, the fence-line has been removed and lowland scrub has replaced the *P.esculentum* community.

(a)

(b)

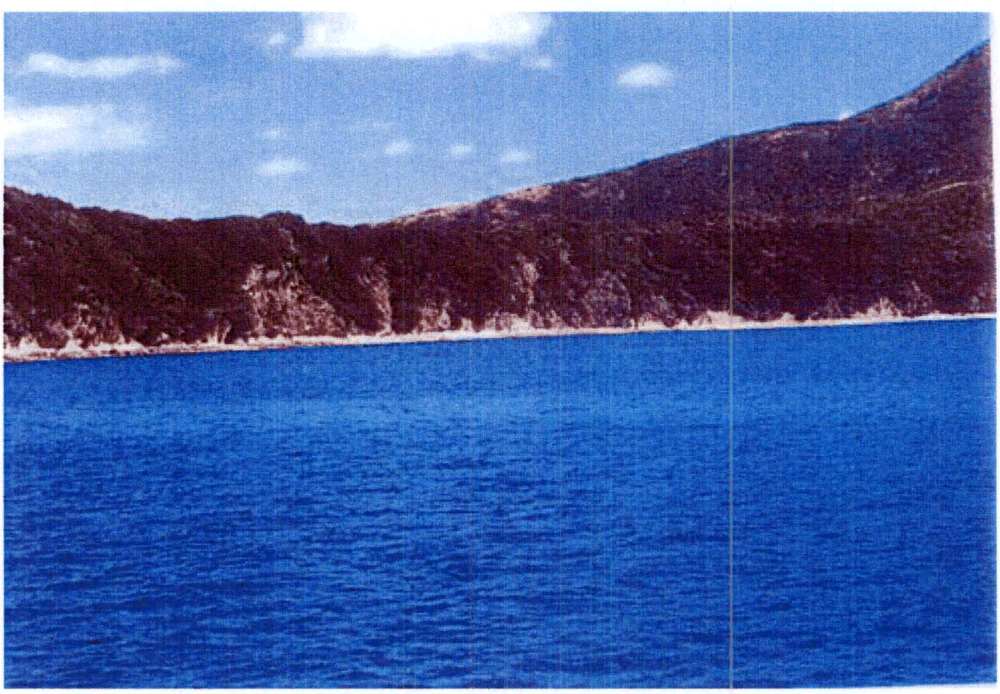
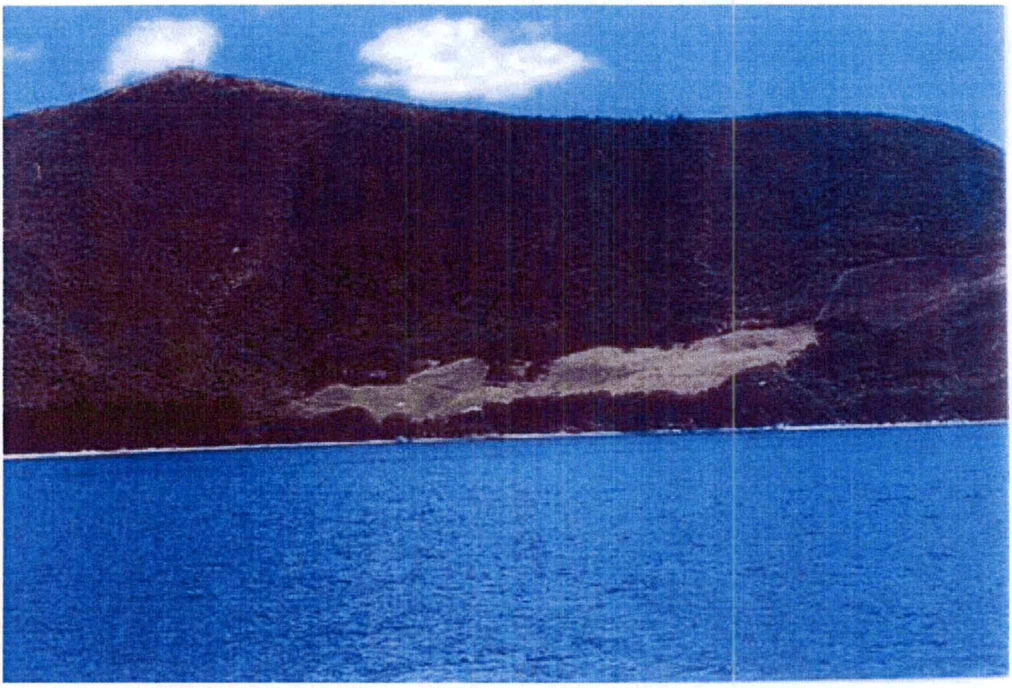


Figure 3.16: Photographs taken at (a) photopoint F1 in 1990 and (b) F2 in 1990. Neither photopoint was retaken in 2001.

(a)



(b)

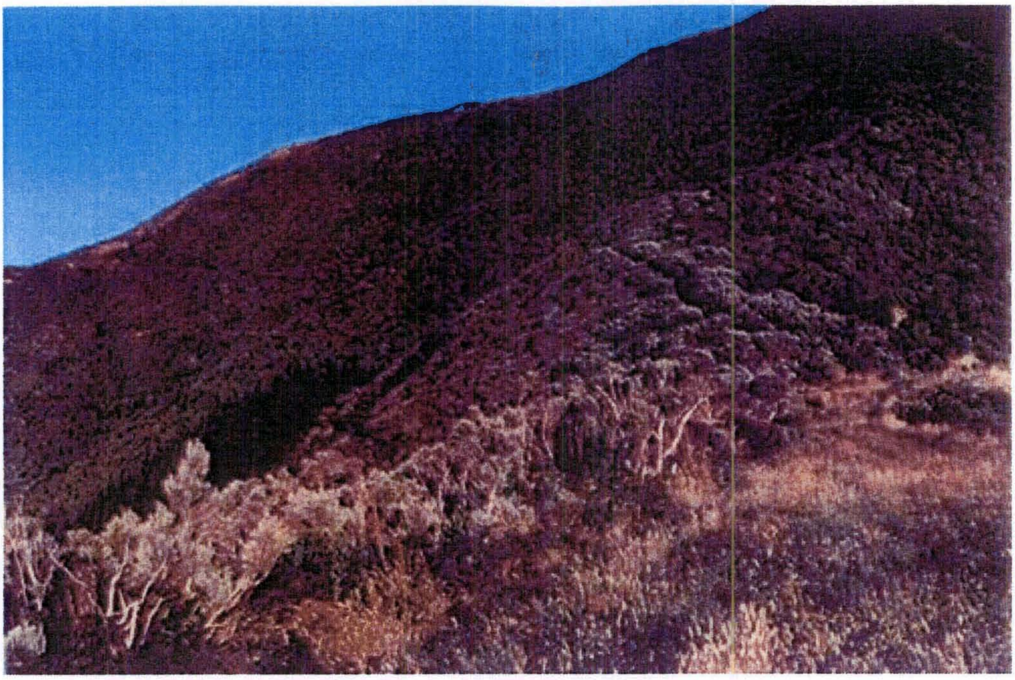
Figure 3.17: Photographs taken from photopoint F3 in (a) 1990 and (b) 2001. From boat looking towards home paddocks. In 1990, the main bush is clearly defined and there are a few lone trees in the paddock. In the 2001 photo, these trees are surrounded by shrub and are fenced. In addition, the scrub along the shoreline is denser and the bottom house is not visible.

(a)

(b)

Figure 3.18: Photographs taken from photopoint G1 in (a) 1990 and (b) 2001. By solar panel shed peninsula. The vegetation in the foreground in 1990 is predominantly *Ozothamnus leptophylla*, grasses and other shrubs; by 2001 *Pseudopanax arboreus* dominates. In 1990, Southwood Point has areas of pasture grasses interspersed with shrub species. In 2001, the shrubs have spread to some areas but a few grass areas are still visible.

(a)



(b)

Figure 3.19: Photographs taken from photopoint G2 in (a) 1990 and (b) 2001. The same vegetation pattern in the foreground in G1 is repeated in G2. *P.esculentum* dominated areas are clearly visible on the hillside to the left of the photo in 1980, with sparse shrubs on the right. In 2001, all areas are covered with dense scrub.

(a)

(b)

Figure 3.20: Photographs taken from photopoint G3 in (a) 1990 and (b) 2001. Looking back up to the summit in 1980 there is low scrub and areas of pasture grass. In 2001, these areas are all dominated by dense scrub except for the mown track.

(a)

(b)

Figure 3.21: Photographs taken from photopoint G4 in (a) 1990 and (b) 2001. The main forest in the centre of the picture in 1990 is clearly defined with scrub on either side; by 2001 there is less definition between the scrub and the forest.

Figure 3.22: Photographs taken from photopoint G5 in 1990. G5 was not re-taken in 2001

(a)

(b)

Figure 3.23: Photographs taken from photopoint H1 in (a) 1990 and (b) 2001. On ridge to Southwood Point.In 1990, vegetation appears to be scrub, predominantly *Ozothamnus leptophylla, Coprosma* sp. and *Pteridium esculentum*, interspersed with bare areas dominated by pasture grasses. There is a small slip in the middle of the photo without any vegetation growing on it. Near the pine trees, the pasture area that is utilized by takahe is clearly visible. In 2001, the slip is not visible and areas of grass are not apparent, except for the pasture area near the pines.

Figure 3.24: Photographs taken from photopoint H2 in 1990. H2 was not re-taken in 2001.

(a)

(b)

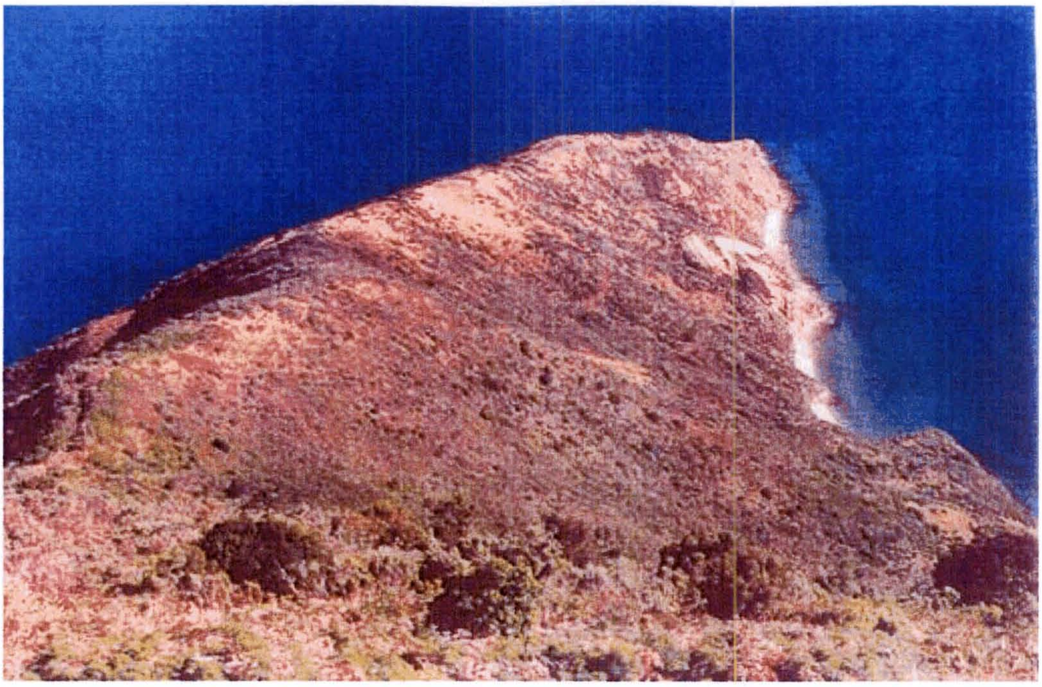
Figure 3.25: Photographs taken from photopoint H3 in (a) 1990 and (b) 2001. In 1990, the scrub is sparse and low and the Ring Road is clearly visible; by 2001 the scrub is denser, taller and the Ring Road is less discernible.

(a)

(b)

Figure3.26: Photographs taken from photopoint H4 in (a) 1990 and (b) 2001. The photo taken in 2001 is further down the ridge due to the denseness of the vegetation. In 1990, the pine plantation is surrounded by sparse scrub and is clearly defined, in 2001, the scrub around the plantation has grown in height and denseness and the plantation's edges are less harsh.

(a)



(b)

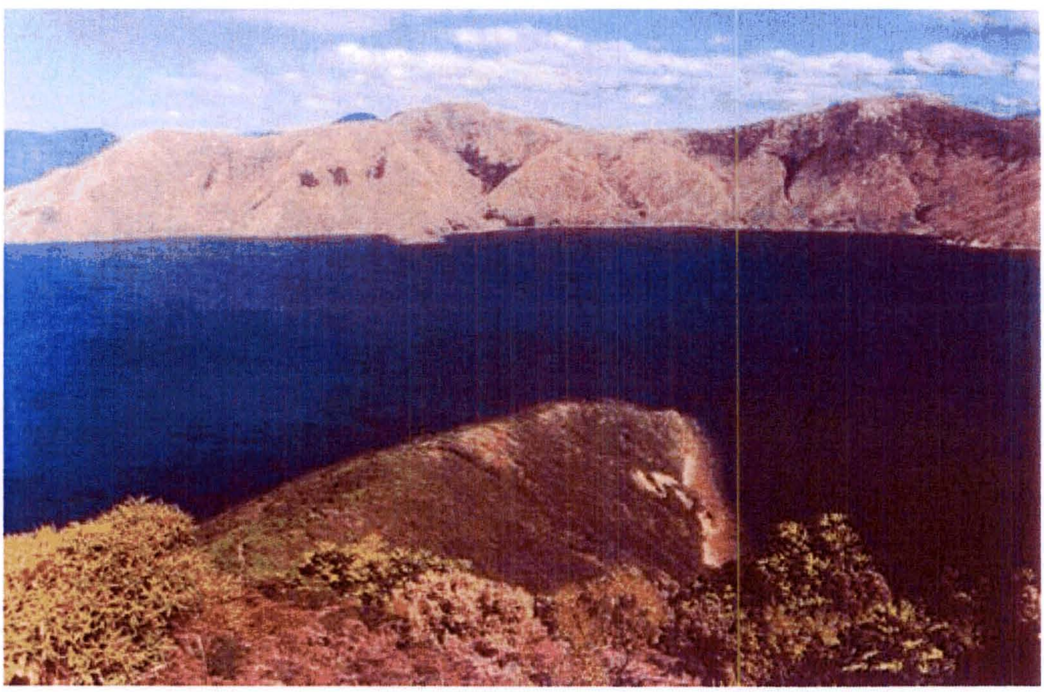
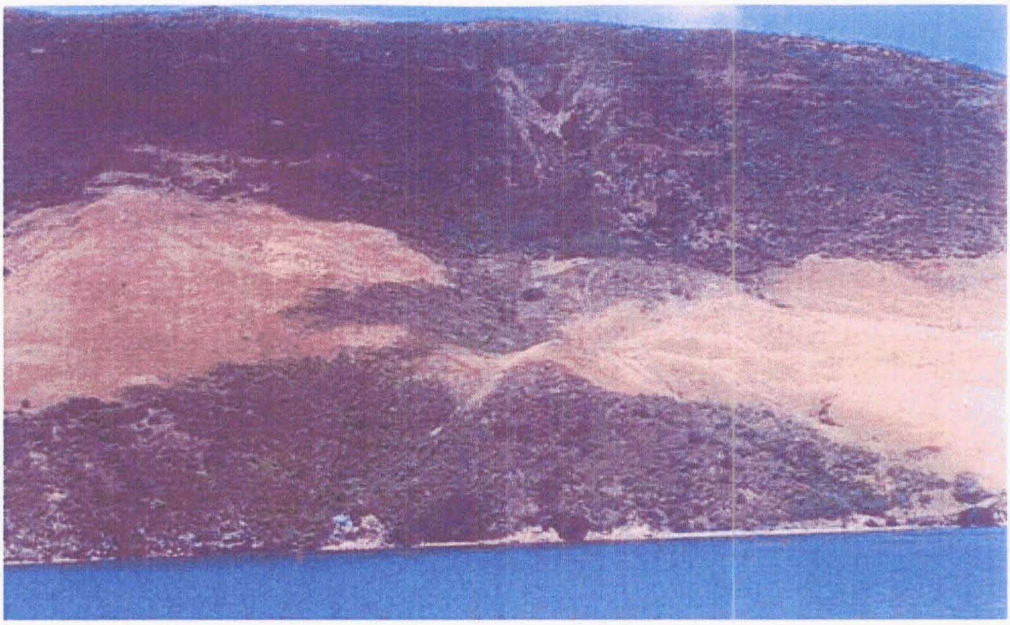


Figure 3.27: Photographs taken from photopoint I in (a) 1990 and (b) 2001. On ridge south-west of summit. Scrub and pasture dominated all areas in 1990. In 2001, less pasture is visible and the scrub is denser.

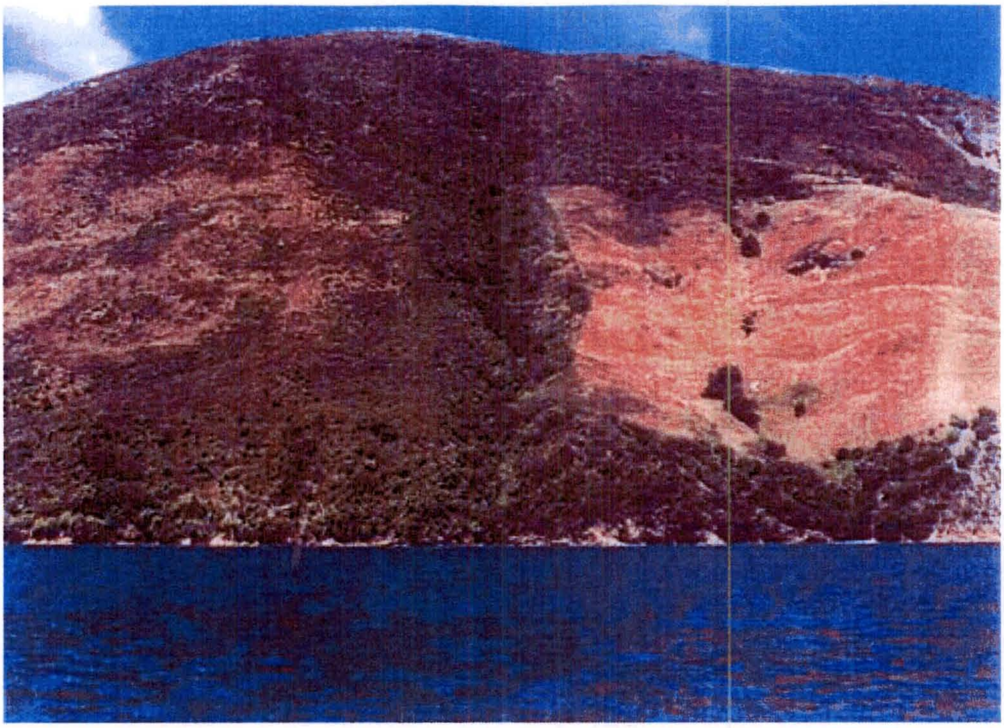
(a)



(b)

Figure 3.28: Photographs taken from photopoint J in (a) 1990 and (b) 2001. The slip in the centre of the 1990 photo is covered in vegetation in the 2001 photo the slip is bare as it re-slipped in 200.1 In all other areas scrub has increased and invaded the pasture areas.

(a)



(b)

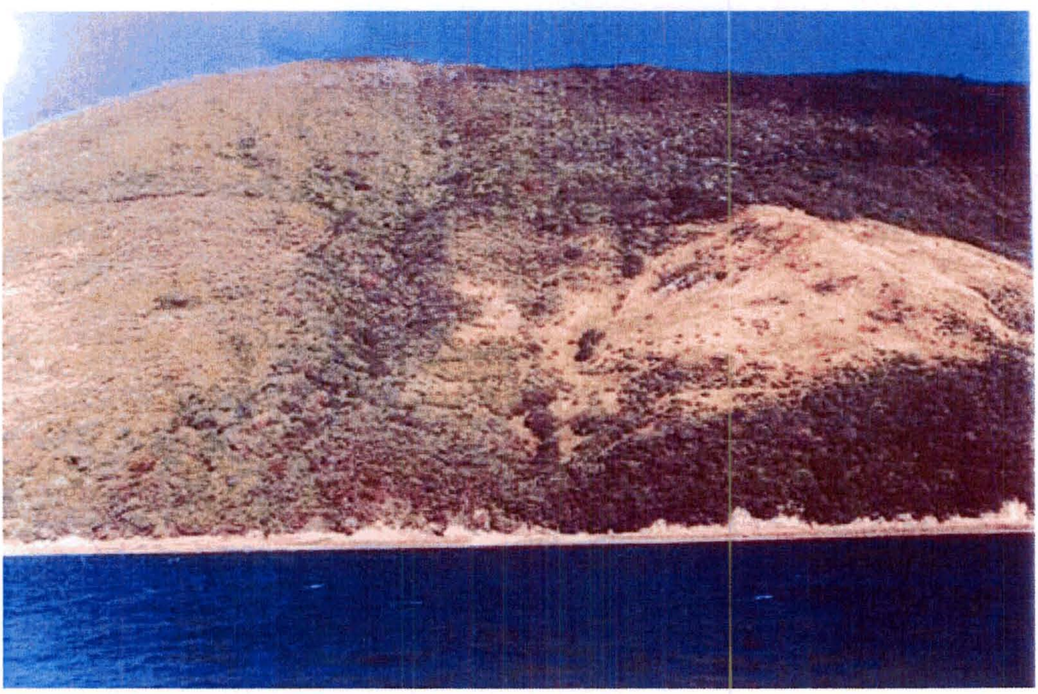


Figure 3.29: Photographs taken from photopoint K in (a) 1990 and (b) 2001. In the 1990 photo, pasture and scrub dominates the left and grazed pasture dominates the right. In 2001, the pasture at the left is dominated by *P.esculentum* and *Erica lusitanica* and the pasture at the right is a mixture of scrub and grasses.

(a)

(b)

Figure 3.30: Photographs taken from photopoint L in (a) 1990 and (b) 2001. From boat towards Woodlands. Woodlands Bush dominates the centre of both photos; however, in the 2001 photo, the edge is less clearly defined due to an increase in scrub in the surrounding area. In 1990, the paddocks at the left have fewer shrubs and are still grazed, in 2001, grazing has been reduced and scrub cover has increased.

(a)

(b)

Figure 3.31: Photographs taken from photopoint M in (a) 1990 and (b) 2001. In 1990, pasture/scrub dominates all areas; by 2001 scrub comprises 95% of this area with a few small areas of pasture.

(a)

(b)

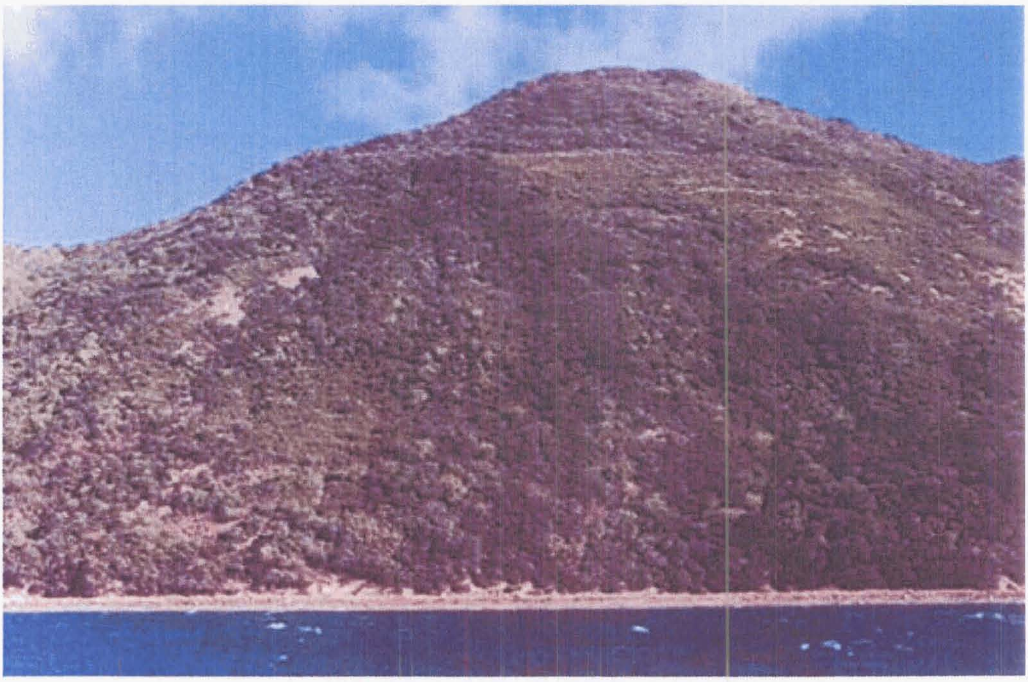


Figure 3.32: Photographs taken from photopoint N in (a) 1990 and (b) 2001. Vegetation in 1990 is predominantly scrub with patches of grass clearly visible. In 2001, vegetation is denser with very few bare areas.

Chapter 4. Discussion

The objectives of this study were to (1) describe, using classification and ordination, the plant communities on Maud Island, (2) identify the important environmental factors underlying variation in plant species composition, and (3) ascertain how the plant communities have changed over time by comparing these results with previous studies of the vegetation of Maud Island.

Using TWINSPAN, I identified eight compositionally-distinct communities on Maud Island and 219 plant species. Exotic species comprised 48% of the flora and native species were 52%. Six plant species dominated the species composition of the plots they were; *Pteridium esculentum, Pseudopanax arboreus, Hebe stricta* var, *stricta, Melicytus ramiflorus, Ozothamnus leptophylla* and *Coprosma robusta.* Plant height and plant composition in each community were influenced by aspect, drainage, topography, human disturbance and to a lesser degree natural disturbance such as landslips. The human influence could be attributed to framing practices such as burning, grazing, fertilizing, construction of fences and buildings and removal of grazing. This was confirmed by the ordination analyses, which showed that plant communities on Maud Island are a reflection of biotic and abiotic factors, both historical and present day.

Over the last twenty years the dominant vegetation on Maud Island has followed a predictable path from a scrub/bracken/grassland community to regenerating coastal forest and tall stature scrubland. The six plant species which dominate the vegetation plots are all early colonizers and were present in the last two studies. This study showed that they are now a main component of several of the plant communities. In the last 20 years the grassland communities have reduced in size due to the reduction in grazing pressure and therefore invasion of scrub species.

Succession of the plant communities on Maud Island has largely been allowed to occur naturally without human restoration attempts (apart from planting for extra food sources for introduced bird species). This study has found that regeneration of the indigenous vegetation on the island is occurring and areas that were farmed have become scrub and will over time become coastal forest, if there is no disturbance. Composition of the plant communities on Maud Island has been affected by the natural introduction of plant species from the mainland. This study found two species that was not present in the previous studies – *Metrosideros umbellate* and *Plagianthus divaricatus.*

The primary factor that has shaped the spatial temporal vegetation patterns on Maud Island appears to have been the pressure of human usage, primarily farming. While the island's vegetation recovers, it is still constrained by past land use history, introduced plant species, a depleted seed bank, plant species extinction, eroded soils and nutrient depletion.

Pteridium esculentum was identified as a dominant species in the two previous studies. This study showed that while bracken was still a dominant plant in some communities, its abundance was declining, likely due to increased shading and competition as succession occurs. *P. esculentum* an integral part of the flora in all three vegetation studies appears to have facilitated regeneration by acting as a soil stabilizer and a nurse crop for seedlings. While tall dense bracken may dominate the vegetation for many years some species such as *Pseudopanax arboreus* and *Coriaria arborea* can invade and grow up through the bracken (Wardle, 1991). This was seen on Maud Island, in many areas there were large numbers of *Pseudopanax arboreus* and *Melicytus ramiflorus* growing under the dense *P. esculentum.* Other studies have shown that an early successional species can facilitate ecological recovery; for example in the Badlands of south-western France the non – indigenous tree *Pinus nigra* ssp. *nigra*, acted as a nurse stand for broad-leafed and herbaceous indigenous species (Vallauri, Aronson & Barbero, 2002). At Hinewai Reserve (Banks , Peninsula, New Zealand). *Ulex europaeus* and *Cytisus scoparius* have acted as nurse crops for taller growing native tree species (Wilson, 1990).

4.1 Plant Community Composition and Distribution in Relation to Environmental Variables

The constrained ordination that was used to relate variation in species composition to the measured environmental variables showed that altitude was the most important environmental variable affecting plant species composition within the communities on Maud Island. Moisture also directly affected the distribution of plant communities across the island. Underlying the environmental factors was a historical disturbance gradient.

On Maud Island several factors have influenced the succession of the plant communities including, site history due to human disturbances, topography, moisture, climate, litter, disturbance and sowing of seeds for farming and planting shrubs. All these factors are clearly impacting on the succession of plant communities and whether the communities reach a stable state or are in a continual state of flux (Cook, 1996).

4.1.1 *Topography*

The topography of Maud Island plays an important part in the distribution of the plant communities. The island is part of a drowned river system, dominated by mountain slopes and steep hills (Walls & Laffan, 1986). I found that over 80% of the plots were on slopes greater than 10° and the average slope was 38.5°. Ordination showed that altitude was one of the most important variables. Altitude on Maud Island goes from sea level to 370 meters this is not very high but in general the slopes became steeper the higher you went. On the steeper slopes vegetation was shorter and scrubbier. This is linked to two factors shallow soils and the water holding capacity of the soil, on steeper slopes water does not percolate into the soil as readily as on flatter areas. (Walker *et al.*, 1995). The flatter areas were used for buildings or pasture. The relationship between topography and plant community composition has been studied by Bartha et al they found a clear relationship between these two factors. Species richness and diversity of species in a tallgrass meadow increased at lower elevations (Bartha, *et al.,* 1995).

4.1.2 *Water*

Water has had a major influence on the location of plant communities on Maud Island. This influence is clearly shown in the primary vegetation classification and the first Axis of the ordination. There are very few water sources on the island, the main water supply flows through the main forest (this may be why the forest was never milled, it protected the water catchment) to the paddocks below; in addition, three other springs occur on this side of the island. On the north-east side of the island only one water source has any value for stock, although there are several small seepage areas (NZWS, 1971) (Appendix 10).

Particular examples of the impact of water on the vegetation communities of Maud Island are the areas that supported mature and regenerating *Dysoxylum spectabile* forest. These areas are predominantly on the south side; they were damper, were less open, had denser canopy cover and had the highest percentage of shade tolerant plants and ferns. In time, *Dysoxylum spectabile* may grow in drier areas of the island as litter builds up and traps moisture. The communities on the north-east side of

Maud Island are drier and are predominantly scrub and grasslands. They were more open and exposed they supported lower species diversity – predominantly pasture.

In an area adjacent to the pines landslides occur infrequently. This area is clearly visible in the aerial photos (Appendices 6, 7, 8). Due to the landslides the vegetation in this area never reaches a higher vegetation cover which would decrease the likelihood of a landslide occurring. Due to the dryness and ongoing disturbance of this area I expect that it may take many years for the main forest species *Dysoxylum spectabile* to establish in these areas if at all.

4.1.3 *Litter*

The percentage of litter in the plant communities did not have a strong influence on the plant composition of Maud Island. However, it must be noted that litter depth and composition has an influence on plant communities and affects above ground and below ground processes (Nilsson *et al.,* 1999). When Ogle surveyed the main forest in 1980 the main forest was more open and therefore drier and there would have been less damp litter which could impact on seed germination. Whereas, this study found a high level of seedlings of many of the canopy species in the understory in the forest. In some areas, particularly the dry exposed sites, regeneration may be faster as the scrub expands and the litter increases adding more nutrients, increasing the water holding capacity and increasing the microbial and invertebrate fauna.

4.1.4 *Climate*

Maud Island's climate has a strong maritime influence. There are few frosts, rainfall varies seasonally influenced by La Nina and El Nino and the close proximity to the North Island, and there is an occasional drought year. In drought years regeneration will be slowed as few seedlings will survive, particularly on the dryer north-west slopes (Cockayne, 1967). Predominant winds are west to north-west (Pascoe, 1983; N.I.W.A., 2000) (Appendix 11). It appears that rainfall has had a strong influence on the plant communities of Maud Island. The forest community clearly shows this; ordination grouped all plant species that preferred damper sites together these plants were represented in high numbers within this community. The areas adjacent to the forest community supported regenerating coastal forest.

Strong salt laden winds during storm events affect the vegetation on Maud Island by causing mortality or necrosis to less tolerant plant species (Levy, 1990). In the coastal scrub areas there appeared to be a correlation between the influence of the salt laden winds and plant species composition. Species that dominated this community were *Phormium cookianum* and *Arthropodium cirratum,* these species are tolerant of coastal conditions (Ogle,1987). Communities closer to the sea often have younger soil (more disturbances); salinity decreases with distance from the ocean; likewise soil nutrients (Young, Shao & Porter, 1995).

4.1.5 *Soil*

When comparing the soil map for Maud Island of Webb and Aitkinson (1982) (Figure with the vegetation map generated by this study several underlying soil patterns can be observed. Much of the island (60%) is dominated by Ketu steepland soils, firm phase. Characteristics of this soil type are shallow soils and stony to bouldery. This soil type predominates on the north-east side of the island and on the southern side of the island in areas closest to the sea. The plant communities associated with this soil type were predominantly coastal and lowland scrub with some forest scrub. The plant species present were all early colonizers and tolerated low nutrient levels and low moisture (Wardle, 1991). The areas that supported pasture and shrubland pasture were Ketu steepland and hill soils friable phase. This soil is the most productive soil on the island; they have good structure, higher nutrients and deeper soil horizons. The soils under the main forest areas and regenerating forest were Ketu steepland soils friable phase. These soils occur on steeper slopes with a shady aspect. The soil profile is shallow, with some stones it may be silty and nutrients may be low. *Dysoxylum spectabile* the main canopy tree within these forests is very tolerant of semi-fertile damp soils (Wardel 1991).Other studies have shown that plant community composition is linked to substrate variables, soil type and drainage (Smale, 1984; Norton, 1994).

4.2 Succession of Plant Communities on Maud Island

Succession of the plant communities on Maud Island can be determined by this study and comparing previous vegetation studies on the island Dix1990 and Ogle 1980.While this study has used more quantitative methods than the previous two studies there is sufficient information too compare and look at general patterns of succession over the last twenty years. Since Ogle's study a lot of the island has been removed from grazing and fencing of several large areas has occurred. This has decreased the number of disturbances and in some areas grasslands are reverting to early successional forest and the main forest has increased in size. Disturbances such as farming practices can influence communities in several different ways depending on frequency of disturbance, scale and intensity. These factors then affect plant species community composition, and where the communities occur over a landscape (Korb and Ranker 2001).

Grazing by sheep, cattle, pigs and goats on Maud Island, like fire, has had an extensive impact on species composition. Stock damage through grazing is a highly complex process; damage is caused through selective consumption of plant material, removal of competitors, trampling and rooting up of the soil surface and the perturbation of water and soil processes. Grazing can be responsible for the depletion of vegetation around the edges of forests and in the forest understorey, increase in openness of the forest and consequently a drier interior. In addition, grazing through selective processes may increase the populations of unpalatable plant species and decrease populations of palatable plant species (West, 1980; McIntyre *et al.*, 1999).

The main forest community on Maud Island is the most intact plant community. This community has increased in size and diversity of plant species since the two previous studies. This study, like that of Dix, found the forest floor carpeted with seedlings of the main canopy species in some areas. The forest on Maud Island was accessible to stock until 1961 when it was fenced. The forest has a depauperate epiphyte community, low numbers, of filmy ferns and few canopy tree species in the five to 12 metre height layer. Increased species richness in the seedling and small shrub layer would indicate a recovery from browsing pressures. This may also be due to fencing of the forest area. Undoubtedly removal of trees from the main forest block for building purposes and fencing would have occurred and this would affect species composition. The effect of this is hard to tell as there is no data detailing what species have been removed and how many and in what area.

Between 1971 and 1972 other areas that were fenced included those either side of the main bush (NZWS, 1971, 1972), these areas now support regenerating coastal forest. Species richness in these areas showed an increase from small shrubs and bracken noted in both previous studies to tall canopy species. These species included *Dysoxylum spectabile, Pennantia corymbosa* and *Weinmannia racemosa* which are the predominant canopy trees in the main forest. In the understory regeneration of all seedlings was high. This is an indication that the removal of grazing from this area in the 1970's has had an impact on species composition.

In late 1972, a fence was put in around the Ring Road to exclude cattle from the upper slopes of Maud Island (NZWS, 1972). Eight years later Ogle classified this area as bracken/scrubland with less than 30% of an area in shrubs and grass and bracken with no shrubs. In 1990 Dix classified this area as Bracken fernland with shrubs and shrubland. This study found that the bracken shrubland was now predominantly forest scrub, coastal scrub and lowland scrub an indication that as grazing pressure has been removed succession is towards higher stature vegetation.

At present some areas on Maud Island are still grazed by sheep. In Ogles and Dixs studies the areas utilized for grazing were of similar size whereas this study showed a decline in these areas. The areas that had been removed from grazing supported the shrubland pasture communities. Sheep maintain the pasture in a suitable condition for the introduced species, takahe, by keeping the grass height down and reducing weed species. Using sheep to manage pasture for endangered birds (Cape Barren geese) has also been used on Chappell Island (350 hectares) in Bass Strait. Managers found that sheep significantly reduced the populations of *Cardus pynocephalus* and *Marrubium vulgare* (Hader, et al, 1999).

Pastoral farming has other problems associated with it: the introduction of weed seeds in pasture seed mixes, unbalancing of nutrient levels due to the over-under use of fertilizers and high chemical levels in the soil due to pesticides and insecticides (Esler, 1987). High levels of DDT and Organochlorines have been detected in the soils on Maud Island (appendix12).Organochlorines while not affecting plant communities may lead to a depurate soil microbe population which could affect soil litter decomposition rates (Esler, 1987).

Firebreaks and paths for the staff have also impacted on Maud Islands plant communities. While they are important to stop further damage by future fires they create disturbance by opening areas to invasion by weeds. This effect is localized and creates a generalized growing opportunity. Pathways used by humans also have higher weed species densities (Hadder *et al*).

All three studies showed that the pine plantation had not spread from its original location. Under the pines there was little or no vegetation growing although there was an area within the plantation that was never planted in pines and which supports several of the key forest canopy species within it. This is interesting, as Brockerhoff *et al.*,(2003) who studied five pine plantations in New Zealand found that under young stands of *Pinus radiata* the early light demanding successional species of grasses and forbes were present moving to the less light demanding seral species such as ferns and indigenous forest species. The lack of understory vegetation may be due to the fact that the plantation was never thinned. Over time as the plantation reaches senenescence more light will filter into the forest floor which may allow regeneration of the forest species.

When comparing plots on the western faces of Maud Island to observations from the two previous studies, it is clear that the grass and small shrubs in these areas have been replaced with larger shrubs and bracken. On this side of the island *Erica lusitanica* was the dominant plant. *E. lusitanica* is a plant that prefers drier sites and is often one of the first plants to colonise and area after fire. *E. lusitanica* re-sprouts readily from burnt stumps after fire. Plant species composition on this side of the island therefore appears to have been driven by a fire regime. Although *E. lusitanica* is an introduced plant it will stabilise the ground, trap water, increase soil litter and will provide a habitat for the native species such as *Pseudopanax arboreus* (Wasilieff, 1982).

Pteridium esculentum is another plant species that indicates that fire, along with other human-induced disturbances, may lead to secondary plant succession within an area. On Maud Island *P. esculentum* was found in all but three of the plots indicating that fire has had an extensive influence on the vegetation. The use of fire on Maud Island began in the late 1880's when the island was first cleared, to the mid 1970's. Fire can cause local extinction of plant species, drive speciation and adaptation of plant species, and destroy soil/seed bank sources and lead to a progressive loss of nutrients in the soil (Wardle,1991). Interestingly neither gymnosperms nor beech are present on Maud Island, is this due to continual fire over many years of farming?

Another key factor that may affect succession in one area –the peninsula is the re-colonization of the petrel burrows. The petrels will burrow underground and trample the ground which will disturb the low vegetation and their excrement will increase the nutrient loading of the surrounding soil (Timmins, Ogle & Atkinson, 1987).

If there is no disturbance of the plant communities on Maud Island succession will continue to be linear, that is moving from an early successional stage to a late successional stage. However in the slip area adjacent to the main pine plantation succession may never reach a climax successional stage due to continual disturbances and then reverting back to an earlier successional stage.

I predict that the main forest will become denser and ferns and lianes will increase in numbers. In the forest/scrub community the canopy will close over, the early successional plants e.g. *Olearia rani, Kunzea ericoides* and *Melicytus ramiflorus* will die out and the forest trees *Dysoxylum spectabile* and *Pennantia corymbosa* will become the dominant species. In the Hawain Islands Woodcock, Perry & Giambelluca, (1999) found that larger canopy trees will provide roosting sites for birds, which in turn will promote seedling establishment in the understory. Therefore I predicted that the large *Dysoxylum spectabile* and *Pennantia corymbosa* will provide roosting sites for birds particularly Kereru which over time will increase species diversity within the main forest areas.

The shrubland and the lowland scrub will change species composition over time from early successional plants to forest species. It is likely that the coastal scrub community will continue to be regularly disturbed by coastal storms, which contribute to increased salinity and erosion of these areas. This disturbance regime is likely to maintain the distinctive species composition in this area. If the shrubland/pasture and pasture areas were allowed to regenerate naturally, bracken would dominate for the first few years followed by the early successional plants then forest species.

In addition, Maud Island is very close to the mainland so it is to be expected that more new plant species, both exotic and endemic, will arrive either via bird feaces, wind, or accidental human introductions. The impact these species have will depend on their autoecology.

4.3 Sources of Colonizing Seeds

Plant species composition on Maud Island has and will continue to be affected by the availability of seed sources. This study did not study the available seed source in the soil bank but it is highly likely that mismanagement over the years has decreased the soil seed bank and may have caused the extinction of several plant species. When disturbances occurred would also impact on plant species composition on Maud. Studies have shown that disturbances in the early part of the growing season leads to higher densities in grass species whereas plant species composition in plant communities disturbed in autumn are determined by the adjacent shrub tree seed availability (Pakeman and Small, 2005 ; Howe and Mirti,2004).Seeds disperse in many ways, including by water, wind, animals and birds. Sea dispersal of plant propogules is an important mechanism by which new species arrive on islands (West,1980). Sea dispersal could explain how the *Plagianthus divaricatus* (which has dry seed capsules) a new species for the island, arrived there. In contrast the majority (70%) of the indigenous trees and 30% of the shrubs of New Zealand plants have fleshy fruit which are dispersed by birds (Burrows, 1994).

Surrounding Maud Island are several large forest reserves (appendix 13) which would be within flying distance of many of the bird species which occur on Maud Island. Canopy plant species within these reserves include; *Dacrydium cupressinum, Dacrycarpus dacrydioides, Nothofagus* sp, *Strebulus banksii* and *Dysoxylum spectabile* (Wassilieff, 1982). In New Zealand it has been shown that kereru are one of the important dispersers of seeds greater than one centimeter and they may disperse seed up to 50 meters from the parent plant (Lord, Markey and Marshall, 2002). On Maud Island flocks of kereru are often seen feeding on the *Chamaecytisus palmensis* trees indicating that the birds are flying between the mainland and Maud Island. An indication that kereru are dispersing seeds was the large amount of seedlings of many species seen under the *C. palmensis* trees; these included *Coprosma* sp., *Rhopalostylis sapida, Corynocarpus laevigatus Ripogonum scandens* and *Cordyline australis* all species readily eaten by kereru (Johnson 1976; Webb *et al.,* 1988). In addition *Dysoxylum spectabile* seedlings were found, in over 60% of the plots. *Dysoxylum spectabile* is the dominant canopy species in the main forest and its seeds would be preferred by kereru as they are greater than one centimeter (Court and Mitchell, 1988).

It is highly likely that *Metrosideros umbellata* arrived on Maud Island via wind currents as Maud Island lies in the Marlborough sounds one of the windiest parts of New Zealand. This species has very light seed which could easily be transported by wind, other species, e.g., *Weinmannia racemosa* (fine seeds) and *Nothofagus* sp. and *Laurelia novae-zelandiae* which both have winged seeds may yet arrive on Maud Island (G. Walls, *pers. comm.,* 2004). Although, for seeds to survive in any new environment, conditions must be conducive to establishment, these conditions include correct temperature, light, moisture, fungus and in some cases, soil bacterial associations.

4.4 Limitations of the Study

This study had several important limitations, listed below. However, I feel they did not impact on the general trends identified by the study.

1. In the two past studies, Dix and Ogle used different methodology to what I used. This precluded more quantitative approaches to analysing the results.
2. Before each transect line was undertaken I used telemetry gear to determine where the resident kakapo were. This was to ensure that the kakapo was not disturbed. If they were on the line I left this line to a later date. However in

one area due to time constraints I was not able to re-visit this area. This meant that one area was not surveyed during this study. However I was able to determine the vegetation composition in this area by using binoculars and talking to the resident DoC workers.

3. The photo-points that Dix took in 1990 did not have GPS points, this made it difficult to relocate the points exactly.

4.5 Recommendations

At present Maud Island is managed by the Department of Conservation who have strict guidelines for access to the island. These guidelines ensure that Maud Island will remain predator and pest- free and that natural succession will continue to occur. From what I found in this study, I make the following recommendations regarding the continuing management of Maud Island:

- That all the *Metrosideros excelsa*, *Hoheria populnea*, *Sophora microphylla*, *Corynocarpus laevigatus* and *Pittosporum crassifolium* are removed from the island. These plants are all outside their natural range and all have the potential to proliferate on the island and displace native plant species. In addition, these plant species may disperse to surrounding conservation land and become problem weeds.
- Consideration should be given to removing the pine plantations and re-vegetating these areas with local endemic plants. While the pines are not spreading they are not a natural component of the ecosystem on Maud Island; therefore it would be prudent to remove them and replant with native species.
- Test soils on the island for organochlorines, this study did not test chemical loading of the soil but tests were undertaken in 1971 and 1993 for DDE, DDD and DDT. Results were very high. If the Department of Conservation are going to continue to use the island for endangered bird species I would recommend that these tests are repeated as DDT has been shown to cause thinning of eggshells in bird species (Campbell, 1996).
- Consider using Maud Island for establishment of threatened plant species from the local area.

4.6 Conclusions

In total, 219 plant species were recorded. Six dominant plant species occurred: *Pteridium esculentum*, *Pseudopanax arboreus*, *Hebe stricta* var. *stricta*, *Melicytus ramiflorus*, *Ozothamnus leptophylla* and *Coprosma robusta.* Sixty-one of the plant species within the plots occurred at less than 2% of the percent cover. Herbs and monocotyledons (predominantly grasses) dominated the flora. The trees and shrubs were mainly indigenous species. Ferns were in low abundance, probably due to the lack of suitable habitat for them.

From data collected during this study and analyzed by TWINSPAN I have described the vegetation on Maud Island as being in eight community types: C1: Pine Plantation, C2: Forest, C3: Forest Scrub, C4: Coastal Scrub, C5: Lowland Scrub, C6: Shrubland, C7: Shrubland/Pasture and C8: Pasture. Community 1 was composed of *Pinus radiata* with some regeneration of native species, C2 was dominated by *Macropiper excelsum - Dysoxylum spectabile - Rhopalostylis sapida*, C3 by *Pseudopanax arboreus - Brachyglottis repanda - Pteridium esculentum*, C4 by *Pseudopanax arboreus - Hebe stricta* var. *stricta - Pteridium esculentum*, C5 by *Hebe stricta* var. *stricta - Leptospernum scoparium - Pteridium esculentum*, C6 by *Pseudopanax arboreus - Pteridium esculentum* - pasture grasses, C7 by *Dactylis glomerata* - exotic weeds - *Pteridium esculentum* and C8 by *Dactylis glomerata - Holcus lanatus.*

While this study has used more quantitative methods than Ogle (1980) and Dix (1991), these studies contained enough qualitative data to give an indication of the community types present on Maud Island at the time, and to therefore, give a basis for comparison of how the island is changing over time. The photo-points set up in 1991 are a valuable tool to indicate how the plant communities have changed. Comparing all three studies has revealed that over time, as the vegetation recovers from human impact and disturbance, succession is occurring. Several plant species had declined in density or had been eliminated since the Ogle (1980) and Dix (1991) studies, indicating succession is taking place.

A comparison between plant species and environmental factors (altitude, aspect, drainage, vegetation cover, moss, litter, exposed soil, exposed rock, faces, ridges, gullies) using canonical correspondence analysis showed a clear relationship between these factors and where plant communities were located. An underlying factor of the plant species and environmental factors ordination was an historical disturbance gradient. While no data was collected to quantify this, historical records show when fences were built and thereby excluding areas from grazing pressures allowing natural succession to occur. These results highlight the fact that the plant communities on Maud Island has been, and still continues to be, affected by human disturbance predominantly farming/grazing.

Evidence of succession of the plant communities is clearly seen when comparing the photo points in 1991 to 2002. In the absence of further major disturbance, the forest scrub, lowland scrub, shrubland and shrubland/pasture communities will eventually develop into coastal lowland forest dominated by *Dysoxylum spectabile.* Species such as ferns and lianas which were under represented within the communities may increase over time as more habitats become available and the forest becomes denser. There will also be an increase in the shade-tolerant species in the under-storey, e.g., *Beilschmiedia tawa* and *Elaeocarpus dentatus.* In addition, other species that are low in numbers at present, e.g., *Ascarina lucida*, will increase in density and may become a dominant component in some of the communities. The coastal scrub community may never become forest as it is too exposed and dry; however, the species composition may change with *Leptospermum scoparium* becoming the dominant species.

At present, areas of pasture on Maud Island are maintained by sheep for the purpose of providing feeding areas for takahe. This study shows that if this management regime was removed, it is likely that the pasture would, over several years, revert to lowland scrub and then to coastal lowland forest.

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APPENDIX 1: Main historical dates for Maud Island.

Year	Event	Source
Pre- European - 1828	Occupation by Ngati Kuia. 5 villages with 20 terraces and 17 pits on the Northwest coast Maud Island, looking over Apuau Channel.	Bell, 1995; Trotter 1974: Brailsford 1997.
1867	John Gibson granted Maud Island by the Crown.	Bell, 1995.
1898	The island was purchased from Gibson by T Clifford.	Bell, 1995.
1899	T. Clifford sold the island to L Tosswill.	Bell, 1995.
1891 - 1895	Post office on Maud (Maude) Island.	Startup, 1983.
1940	P Mills discovered the rare frog *Leiopelma hamiltoni* on Maud Island.	Crook, Aitkinson and Bell 1971.
1914	Tosswill's estate sold the island to two brothers P.E and C.H Mills.	Bell, 1995.
1946	P. E Mills purchased his brothers share.	Bell, 1995.
1955	Mills sold the island to A. W. Jones.	Bell, 1995.
1950 - 1960	Pigs allowed in bush areas	Wildlife Service No 30/3/24.
1957	Jones sold the island to E.J Rob	Bell, 1995.
1961 (July)	Main Bush fenced.	Wildlife Service No 30/3/24.
1969	E. J Shand bought the island from Rob.	Bell, 1995.
Early 1970's	Goats removed off island	Wildlife Service No 30/3/24
1970	Shand gifted the 18ha of remnant bush to the government as a private reserve and named it Tom Shand Reserve.	Bell, 1995.
1971	Shand gifted the reserve to the Crown.	Bell, 1995.
1971 (December)	Five tons of superphosphate spread on reserve areas.	Wildlife Service No 30/3/24.
1971-1972	Ring fencing of reserve block.	Wildlife Service No 30/3/24.
1972	Five tons of superphosphate spread on reserve areas.	Wildlife Service No 30/3/24.
1972 (April)	Eight robins transferred to Maud Island from the Chetwood Islands.	Wildlife Service No 30/3/24.
1972 (August)	20lb of Yorkshire fog sown to improve habitat for Takahe. Two robins observed in Boat Bay bush.	Wildlife Service No 30/3/24.
1972	Full survey of flow of springs on Island by Forest Protection Advisory Committee (F.P.A.C)	Wildlife Service No 30/3/24.
1972	Road put in to divided upper ungrazed areas (approximately 200 acres) and lower grazed areas (Ring Road). Fencing put in to restrict cattle from upper area.	Wildlife service No 30/3/25

1973	Shand gifted the top 1/3rd of the island (62 ha) to the crown.	Bell, 1995.
1974 (April)	2 male Kakapo transferred to Maud Island from Esperance Valley, Milford.	Merton 1976.
1975 (March)	1 male Kakapo transferred form Fiordland to Maud Island.	Merton 1976.
1974-1975	400 autumn fruiting trees and shrubs planted on Maud Island. Included *Coprosma* sp, *Astelia* sp carrots, sunflower, toetoe, apples, pears, crab apples, spaniard, grasses, cherries, plums, raspberries, grapes, wheat and corn.	Merton 1976
1975 (August)	60lb perennial rye grass, 30lb white clover, 30lb lotus major, 25lb oats and 10lb of sunflower seed planted for Kakapo on eastern side of Maud Island	Wildlife Service No 30/3/24.
1975 (November)	The crown purchased Maud Island from Mr Shand with money raised by public subscription spearheaded by The Forest and Bird Society.	Bell 1995.
1976 (August)	50 toetoe plants from Duncan and Davies planted.	Wildlife Service No 30/3/24.
1977	Transfer of Cook Strait giant weta from Mana Island to Maud Island.	Brown 2000.
1977 (March)	Garden snails inadvertently released on Island from food scraps.	Wildlife Service No 30/3/24.
1977 (October)	Nanny goat found on Maud Island and eradicated	Wildlife Service No 30/3/25.
1979	Maud Island gazetted as a nature Reserve.	Brown 1972.
1979 (June)	10, 000 taupata (*Coprosma repens*) trees planted by Marlborough Forest and Bird Society, around shoreline.	Peace 1979 Wildlife Service No 30/3/24.
1980	South Island Saddelback introduced to Maud from islands near Stewart Island	Cemmick. &, Veitch 1987.
1980(December) – 1981 (January)	C. Ogle surveyed the vegetation on Maud Island and compiled a vegetation map and a report on the flora of Maud Island.	Ogle 1981.
1981	Wildlife Service trainee committed suicide on Maud Island.	Wildlife Service No 30/3/24.
1981	Two paddocks fenced on ridge near fort 3.	Wildlife Service No 30/3/24.
1981	20,000 taupata planted by Forest and Bird on ridge leading to Southwood Point, above and below the ring road. In addition, 200 tree lucerne planted on bare slopes.	Annual Report Maud Island. 1981.
1981	25 puhutukawa (*Metrosideros excelsa*) planted on foreshore and near gun emplacement.	Annual Report Maud Island. 1981.
1981	All pines removed except for Cable Bay, Boat Bay and Homestead Bay.	Annual Report Maud Island. 1981.
1981-1982	1 male and 3 female Kakapo transferred from Stewart Island to Maud Island.	Kakapo Recovery Plan No21.
1982	Gazetted as a Scientific Reserve.	Brown 1992.
1982	2 female and 2 male Kakapo transferred from Maud Island to Little Barrier Island.	Kakapo Recovery Plan No21.
1983	5.000 taupata trees planted; unsure where.	Annual Report Maud Island. 1984.
1990 (January)	Judy Dix updated Colin Ogles vegetation map.	Pers comm C. Ogle.

APPENDIX 2: Site and environmental parameters recorded for each plot.

1) RECCE description number which encompasses the transect line number and plot number
2) The area describes the approximate location of the plot with a quick sketch including prominent landscape features eg slips
3) The date – day-month-year
4) Who described the plot, who recorded the plot
5) Altitude
6) Aspect
7) Slope
8) Physiography broken down into four categories – ridge (including spurs), face, gully, and terrace
9) Soil type according to Webb & Atkinson
10) Cultural – human interference eg grazing
11) Ground cover – the percentage of live vascular vegetation, moss, litter, bare ground, rock. The percentage may be more than 100% due to the layering of plants, soils, litter (S. Wiser, *pers comm..,* 2001).
12) Surface characteristics – presence or absence of rock on surface, size of rock, whether it is bedrock or loose rock.
13) Drainage- good –fast runoff and little accumulation of water; medium – runoff would be slow and water would accumulate for a day or two after rain; poor – where water stand s for a long time (Allen, 1992).
14) Browsing of vegation by other species, eg insect, sheep.
15) Birds positively seen or heard within the plot area (Whitteker, 1967; Allen, 1992).

APPENDIX 3: Species lists of all 219 species observed on Maud Island between 1/2/2000 and 12/7/2001.

Indigenous trees and shrubs.

Latin Name	Common Name	Where Observed	Planted
Alectryon excelsus	Titoki	Forest and regenerating scrub areas	No
Aristotelia serrata	Makomako, Wineberry	Forest and regenerating scrub areas	No
Ascarina lucida	Hutu	Regenerating scrub areas	No
Beilschmiedia tawa	Tawa	Forest and regenerating scrub areas	No
Brachyglottis repanda	Rangiora	Regenerating scrub areas	No
Carpodetus serratus	Putaputaweta, Marble leaf	Forest and regenerating scrub areas	No
Coprosma grandifolia	Raurekau	Regenerating scrub areas	No
C. propinqua	Mingimingi	Regenerating scrub areas	No
C. propinqua x C. robusta		Regenerating scrub areas	No
C. rhamnoides		Regenerating scrub areas	No
C. repens	Taupata	Open areas, regenerating scrub	Yes
C. robusta	Karamu	Regenerating scrub areas	Yes
Coriaria arborea	Tutu	Regenerating scrub areas, track edges	No
Corynocarpus laevigatus	Karaka	Zigzag track	Yes
Cyathodes juniperina	Prickly mingimingi	Te Pakaka Point, Peninsula	No
Dodonaea viscosa	Akeake	Regenerating scrub areas	No
Dysoxylum spectabile	Kohekohe	Forest and regenerating scrub areas	No
Elaeocarpus dentatus	Hinau	Forest and regenerating scrub areas	No
Fuchsia excorticata	Kotukutuku, Native fuchsia	Forest and regenerating scrub areas	No
Gaultheria antipoda	Bush snowberry	Open areas, regenerating scrub	No
G. aparina		Open areas, regenerating scrub	
Griselinia littoralis	Papauma, Broadleaf	Forest and regenerating scrub areas	No
G. lucida	Puka	Forest and regenerating scrub	No

		areas, coastal cliffs	
Hebe elliptica	Kökömuka	Coastal cliffs, Starvation Bay	
H. speciosa		Fort area	Yes
Hebe stricta var. *stricta*	Koromiko	Open areas, regenerating scrub	No
Hebe stricta var. *macroura*		Open areas, regenerating scrub	No
Hoheria sexstylosa	Lacebark		Yes
Knightia excelsa	Rewarewa, New Zealand honeysuckle	Forest and regenerating scrub areas	No
Kunzea ericoides	Kanuka	Open areas, regenerating scrub, mainly lower altitude	No
Laurelia novae-zelandiae	Pukatea	Main bush	No
Leptospernum scoparium	Manuka	Regenerating scrub areas	No
Lophomyrtus bullata	Ramarama	Regenerating scrub areas, near summit	No
L. obcordata x bullata		1 on Peninsula and 1 in Milk Tree Paddock	No
Macropiper excelsum	Kawakawa, Peppertree	Regenerating scrub areas	No
Melicytus lanceolatus	Mahoe wao	Regenerating scrub areas	No
M. obovatus		Regenerating scrub areas, coastal areas Boat Bay and Starvation Bay	No
M. ramiflorus	Whiteywood	Regenerating scrub areas	No
Metrosideros diffusa		Open areas, regenerating scrub and forest	No
M. excelsa	Pohutukawa	Coastline near wharf, sea cliffs near gun emplacement	Yes
M. perforata		Starvation Bay	No
Muehlenbeckia australis	Pöhuehue	Regenerating scrub areas, lower altitude	No
Myoporum laetum	Ngaio	Coastline near wharf	Yes
Myrsine australis	Mapou, Red matipo	Regenerating scrub areas	No
M. salicina	Toro	Regenerating scrub areas	No
Nertera depressa		Regenerating scrub areas	No
Nestegis lanceolata	White maire	Bush areas	
Olearia paniculata	Akeake	Regenerating scrub areas	No
O. rani	Heketara	Regenerating scrub areas	No
Ozothamnus leptophylla	Tauhinu	Regenerating scrub areas	No
Parsonsia heterophylla	New Zealand jasmine	Open areas in forests	No

Pennantia corymbosa	Kaikomako	Forest and regenerating scrub areas	No
Pimelea urvilleana		Summit, Cable Bay	No
Pittosporum crassifolium	Karo	Kakapo enclosure near paddocks	Yes
P. tenuifolium	Kohu	Regenerating scrub areas, forest	No
Plagianthus divaricatus	Saltmarsh ribbonwood	3 plants only Boat Bay near isthmus	No
Prumnopitys ferruginea	Miro Brown pine	Forest areas	No
Pseudopanax arboreus	Five finger	Regenerating scrub areas	No
P. laetus		Regenerating scrub areas	Yes
Rhopalostylis sapida	Nikau	Forest and regenerating scrub areas	No
Ripogonum scandens	Supplejack	Forest and regenerating scrub areas	No
Rubus cissoides	Bush lawyer	Regenerating scrub areas	No
Schefflera digitata	Pate	Forest areas	No
Solanum aviculare	Poroporo	Open areas regenerating scrub	No
Sophora microphylla	Köwhai	Top of zigzag track	Yes
Streblus banksii	Towai, Large-leaved milk tree	One large tree on beach, many seedlings on west side of island near Westlands/Milk Tree Paddocks	No
Weinmannia racemosa	Kamahi	Forest and regenerating scrub areas	No

Indigenous herbaceous species

Latin Name	Common Name	Where Observed	Planted
Acaena anserinifolia	Piripiri, Bidibidi	Open areas, regenerating scrub	No
A. novae-zelandiae	Piripiri, Bidibidi	Open areas, regenerating scrub	No
Apium prostratum	Shore parsley	Starvation Bay	No
Arthropodium cirratum	Rengarenga, Rock lily	Lower altitudes, open areas, regenerating scrub	No
Caladenia sp.	Sun orchid	Peninsula track	No
Carex virgata		Coastal areas	No
Centella uniflora		Pasture	No
Cortaderia richardii	Toetoe	Lower altitudes, open areas, regenerating scrub	Yes
Deyeuxia avenoides		Open areas regenerating scrub	No
Disphyma australe	Horokaka, native ice plant	Coastal areas	No
Elymus solandri	Blue wheat grass	Coastal areas	No
Euchiton gymnocephalus		Banks of tracks	No
Freycinetia banksii	Kiekie	Forest	No
Gahnia setifolia		End of isthmus, slip above woodlands	No
Galium propinquum	Bedstraw	Peninsula track	No
Geranium microphyllum	A cranesbill	Pasture	No
Haloragis erecta	Toatoa, Salt grapes	Pasture and tracks	No
Helichrysum filicaule		Summit, peninsula	No
Hydrocotyle spp.	Pennywort	Damp, open areas	No
Isolepis cernua		Starvation Bay	No
I. inundata		Coastal cliffs	No
I. nodosa		Around coast line, most bays	No
Juncus gregiflorus	Native rush	Damp, open areas	No
J. pallidus	Giant rush	Paddocks	
Lagenifera pumila	Papatäniïwhaniwha	Peninsula track	No
Linum spp.	Rahuia, Linen flax	Open scrub areas	No
Lobelia anceps		Coastal near home paddock	No
Luzula banksiana	Coastal woodrush	Coastal areas Boat Bay and Starvation Bay	
Microlaena stipoides	Meadow rice grass	Pasture, open areas, regenerating scrub	Yes
Microtis unifolia	Small onion orchid	Summit	No
Oxalis exilis	Yellow oxalis	Boat Bay near Isthmus	No
Oxalis rubens		Open areas, pasture, tracks	No
Parietaria debilis		Banks of tracks	No
Phormium cookianum	Mountain flax	Open areas, regenerating scrub	Yes
Poa cita	Silver tussock	Open areas, regenerating scrub	No
Pterostylis banksii	Green-hooded orchid	Tracks, open areas, regenerating scrub	No
Ranunculus reflexus	Native buttercup	Peninsula track	No
Raoulia glabra		Banks of track above pasture	No
Rytidosperma racemosum		Pastures, open areas, regenerating scrub	No

Sarcocornia quinueflora	Glasswort	Saltmarsh, Starvation Bay and Te Paka Point	No
Senecio glomeratus	Native groundsel	Banks of tracks	No
S. minimus	Native groundsel	Banks of tracks	No
Thelymitra pauciflora	Blue sun orchid	Isthmus, peninsula	No
Urtica ferox	Nettle	Bottom main forest	No
Uncinia uncinata	Hooked sedge	Tracks, open areas, regenerating scrub	No

Introduced trees and shrubs

Latin Name	Common Name	Where Observed	Planted
Chamaecytisus palmensis	Tree lucerne	Near tracks, open areas, regenerating scrub	Yes
Cotoneaster conspicuua	.	Near water collection point summit	Yes
Clematis vitalba	Old man's beard	Open areas, regenerating scrub	No
Cornus capitata	Dogwood	Kakapo area, woodlands	Yes
Cupressus macrocarpa	Monterey cypress	Cliff faces near wharf	No
Cytisus scoparius	European broom	Boat Bay	No
Erica lusitanica	Spanish heath	Open areas, regenerating scrub	No
Eucalyptus globulus	Tasmanian blue gum	Near Comalco Lodge	Yes
E. leucoxylon	Flowering gum	Kakapo enclosures	Yes
Laburnum anagyroides	Laburnum	Near water collection point summit	
Malus sp.	Apple	Summit	Yes
Pinus radiata	Monterey pine	Pine plantations	Yes
Ribes grossularia	Gooseberry	Kakapo enclosures	Yes
Sorbus aucuparia	Rowan	Zigzag track	Yes
Teline monspessulana	Montpellier broom	Open areas, regenerating scrub	No
Ulex europaeus	Gorse	Near summit, west side of island	No
Vitis sp.	Grape	Kakapo enclosure	Yes

Introduced herbaceous species

Latin Name	Common Name	Where Observed	Planted
Achillea millefolium	Yarrow	Pasture and open areas, regenerating scrub	No
Agrostis capillaris	Brown top	Pasture and open areas, regenerating scrub	Yes
Bellis perennis	Daisy	Pasture	No
Bromus hordeaceus	Soft brome	Pasture and open areas, regenerating scrub	
Capsella bursa-pastoris	Shepherd's purse	Pasture	No
Carex otrubae		Coastline Boat Bay near isthmus	No
Chenopodium album	Fathen	Open areas, pasture, tracks	No
Cerastium fontanum ssp. *vulgare*	Mouse-ear chickweed	Pasture	No
C. glomeratum	Annual mouse-ear chickweed	Pasture	No
Conyza albida		Pasture and open areas, regenerating scrub	No
Cortaderia spp.	Pampas grass	Zigzag track near summit	Yes
Cirsium vulgare	Scotch thistle	Pasture and open areas, regenerating scrub	No
Crepis capillaris	Hawksbeard	Pasture, open areas, regenerating scrub	No
Dactylis glomerata	Cocksfoot	Pasture and open areas. regenerating scrub	Yes
Digitalis purpurea	Foxglove	Pasture and open areas, regenerating scrub	No
Ehrharta erecta	Veld grass	Open areas, pasture	No
Erodium circutarium	Storksbill	Pasture and open areas, regenerating scrub	No
Festuca rubra		Pasture and open areas, regenerating scrub	Yes
Galium aparine	Cleavers	Open areas, pasture	No
Geranium dissectum	Cut-leaved geranium	Pasture and open areas	No
Holcus lanatus	Yorkshire fog	Pasture and open areas, regenerating scrub	Yes
Hordeum murinum	Barley grass	Pasture and open areas, regenerating scrub	Yes
Hypochoeris radicata	Cat's-ear	Pasture and open areas, regenerating scrub	No
Linum bienne	Pale flax	Open areas, pasture, tracks	No
L. monogynum	Linen flax	Coastal scrub	No
L. trigynum	Yellow flax	Open areas, pasture, tracks, mainly west side of island	No
Lolium perenne	Perennial ryegrass	Pasture and open areas, regenerating scrub	Yes
Lotus pedunculatas	Lotus	Open areas, regenerating scrub	Yes

Medicago lupulina	Black medick	Pasture and open areas, regenerating scrub	No
Oxalis incarnata	Lilac oxalis	Near buildings	No
Orobanche minor	Broomrape	Pasture and open areas, regenerating scrub	No
Plantago lanceolata	Narrow leaf plantain	Open areas, pasture, tracks	No
P. major	Broad leaf plantain	Open areas, pasture, tracks	No
Prunella vulgaris	Self heal	Open areas, pasture, tracks	No
Pseudognaphalium luteo album	Jersey cudweed	Open areas, pasture, tracks	No
Ranunculus parviflorus	Small-leaved buttercup	Open areas, pasture, tracks	No
Rubus sp. "Marcus"	Raspberry	Cleared area near house and kakapo enclosure	Yes
Rumex acetosella	Sheep's sorrel	Open areas, pasture, tracks	No
R. crispus	Curly-leaf sock	Damp pasture	No
Senecio jacobaea	Ragwort	Pasture and open areas, regenerating scrub	No
Silybum marianum		Coastline Boat Bay near isthmus	No
Sisymbrium orientale	Oriental mustard	Open areas, pasture	No
Solanum nigrum	Black nightshade	Regenerating scrub	No
Stellaria media	Chickweed	Pasture, open areas, regenerating scrub	No
Taraxacum officinale	Dandelion	Pasture and open areas, regenerating scrub	No
Trifolium sp.	Clover	Pasture	Yes
Verbascum thapsus	Wooly mullein	Open areas, Pasture	No
Veronica arvensis	Field speedwell	Pasture	No
V. persica	Scrambling speedwell	Pasture and open areas, regenerating scrub	No
Vicia sativa	Vetch	Open areas, regenerating scrub	No

Ferns and fern allies

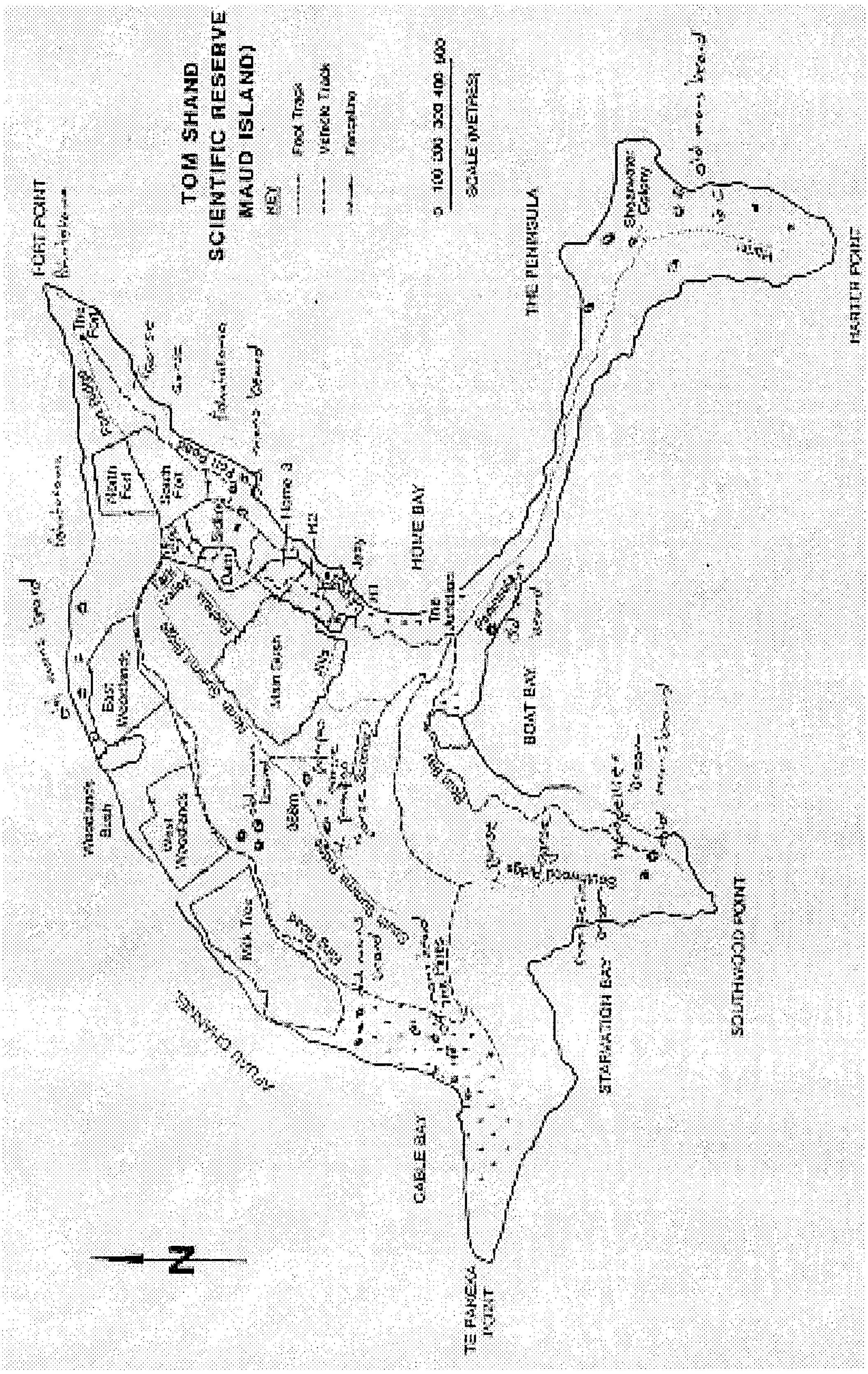
Latin Name	Common Name	Where observed
Adiantum cunninghamii	Maidenhair fern	Coastal open areas
Arthropteris tenella		Forest
Asplenium bulbiferum s.s.	Mouku, Hen and chicken fern	Open areas, regenerating scrub, forest
A. flabellifolium	Necklace fern	Summit and Te Pakeka Point coast
A. flaccidum	Makawe, Hanging spleenwort	Open areas, regenerating scrub, forest
A. gracillimum		Forest areas
A. oblongifolium	Huruhuru whenua, Shining spleenwort	Regenerating scrub areas
A. polyodon	Petako, Sickle spleenwort	Forest areas
A. terrestre		Starvation Bay coast
Blechnum blechnoides		Starvation Bay coast
B. chambersii	Rereti	Forest
B. discolor	Piupiu, Crown fern	Regenerating scrub, forest
B. filiforme	Pänako, Climbing blechnum	Forest and regenerating scrub areas
B. fluviatile	Kiwikiwi, Creek fern	Forest and regenerating scrub areas
B. montanum		Along tracks
B. novae-zelandiae	Kiokio	Open areas, regenerating scrub
B. vulcanicum		Banks of tracks, wetter areas
Cheilanthes distans		Coastal area near Milk Tree Paddock
Cyathea dealbata	Ponga, Silver fern	Open areas, regenerating scrub
C. medullaris	Mamaku, Black tree fern	Open areas, regenerating scrub
Grammitis ciliata	Hairy grammitis	Bush areas
Histiopteris incisa	Mätätä, Water fern	Wetter areas, regenerating scrub
Hypolepis ambigua		Starvation Bay / Boat Bay coast
Hymenophyllum s.p.p.		Forest and forest scrub areas
Lastreopsis glabella		Forest
L. hispida	Tuakura, Hairy fern	Forest
L. microsora		Open areas, regenerating scrub
Lycopodium volubile	Climbing clubmoss	Open areas, regenerating scrub
L. scariosum	Creeping clubmoss	Zigzag track banks
Microsorum pustulatum	Köwaowao, Hound's tongue fern	Forest and regenerating scrub areas
M. scandens	Mokimoki, Fragrant fern	Forest and regenerating scrub areas
Paesia scaberula	Ring fern	Open areas, regenerating scrub, pasture
Pellaea rotundifolia	Tarawera, Button fern	Forest and regenerating scrub areas
Pneumatopteris pennigera	Päkau, Gully fern	Forest and regenerating scrub areas
Polystichum richardii	Pikopiko, Common shield fern	Open areas, regenerating scrub
P. vestitum	Pūniu, Prickly shield fern	Regenerating scrub
Pteridium esculentum	Bracken	Open areas, regenerating scrub
Pteris macilenta	Titipo, Sweet brake	Forest
Pyrrosia eleagnifolia	Ngärara Wehi, Leather leaf fern	Rocky area summit, coastal areas Te Paka Point

13. APPENDIX 4: Three letter abbreviations used in DCA and CCA ordination diagrams.

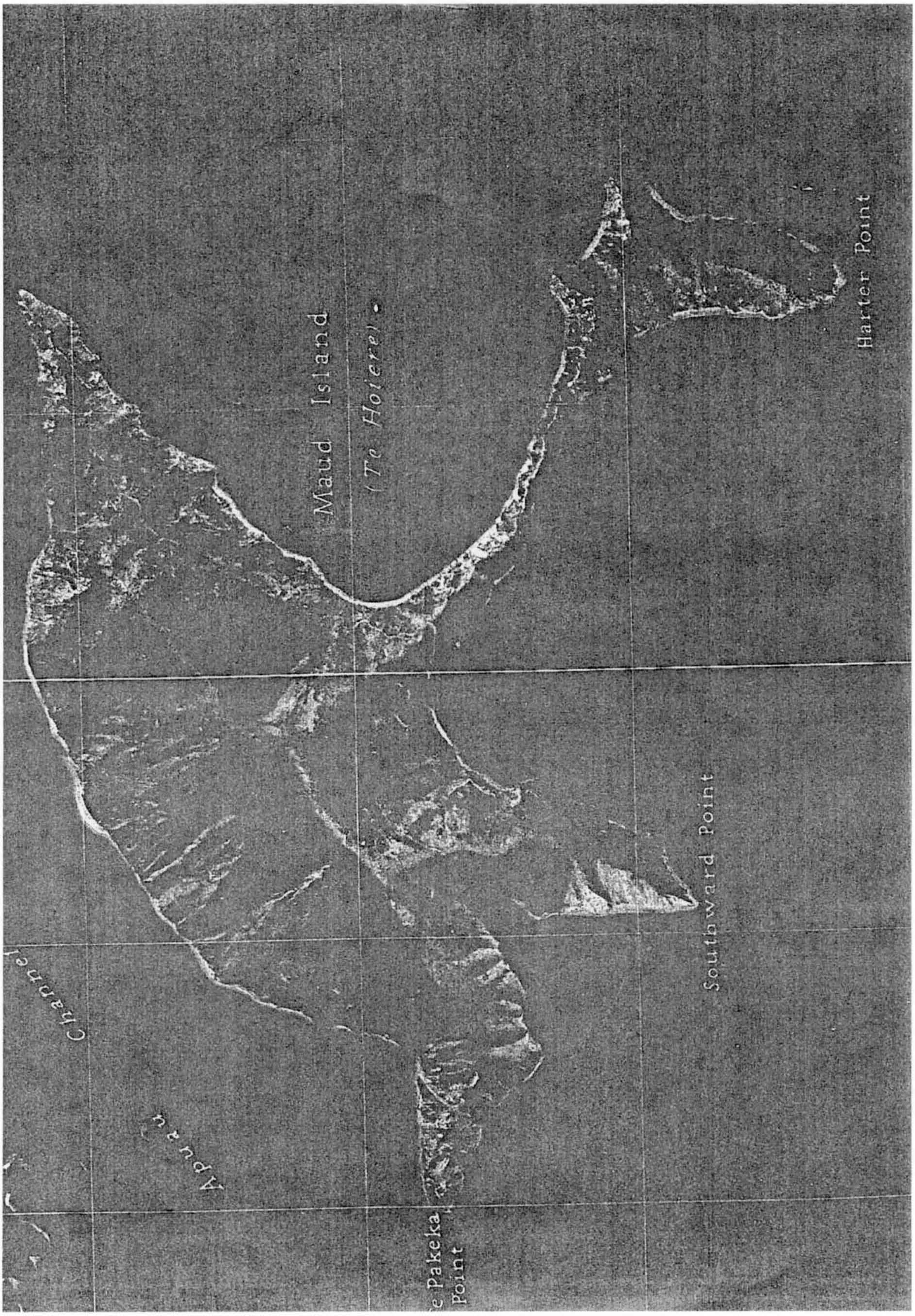
Abbreviation	**Scientific name**
ACANOV	*Acaena novae-zelandiae*
ACHMIL	*Achillea millefolium*
AGRCAP	*Agrostis capillaris*
ALEEXC	*Alectryon excelsus*
ARISER	*Aristotelia serrata*
ASCLUC	*Ascarina lucida*
ASPBUL	*Asplenium bulbiferum* s.s
ASPFLA	*A. flaccidum*
ASPOBL	*A. oblongifolium*
ASPPOL	*A. polyodon*
BEITAW	*Beilschmiedia tawa*
BLECHA	*Blechnum chambersi*
BLEFIL	*B. filiforme*
BLEFLU	*B. fluviatile*
BLENOV	*B. novae-zelandiae*
BRAREP	*Brachyglottis repanda*
BROHOR	*Bromus hordeaceus*
CARSER	*Carpodetus serratus*
CASLEP	*Cassina leptophylla* (new name- *Ozothamnus leptophylla*)
CERGLO	*Cerastium glomeratum*
CHAPAL	*Chamaecytisus palmensis*
CHEALB	*Chenopodium album*
CIRVUL	*Cirsium vulgare*
CONALB	*Conyza albida*
COPPRO	*Coprosma propinqua*
COPREP	*C. repens*
COPRHA	*C. rhamnoides*
COPROB	*C. robusta*
CORARB	*Coriaria arborea*
CORLAE	*Corynocarpus laevigatus*
COTCON	*Cotoneaster conspicuua*
CRECAP	*Crepis capillaris*
CYADEA	*Cyathea dealbata*
CYAMED	*C. medullaris*
CYTJUN	*Cyathodes juniperina*
DACGLO	*Dactylis glomerata*
DIGPUR	*Digitalis purpurea*
DYSSPE	*Dysoxylum spectabile*
ERILUS	*Erica lusitanica*
FESRUB	*Festuca rubra*
FUCEXC	*Fuchsia excorticata*
GALAPA	*Galium aparine*
GAUANT	*Gaultheria antipoda*
GRILIT	*Griselinia littoralis*
HEBSTR	*Hebe stricta* var. *stricta*
HOLLAN	*Holcus lanatus*
HORMUR	*Hordeum murinum*
HYPRAD	*Hypochoeris radicata*
JUNGRE	*Juncus gregiflorus*
JUNPAL	*J. pallidus*
KNIEXC	*Knightia excelsa*
KUNERI	*Kunzea ericoides*
LEPSCO	*Leptospernum scoparium*
LINMON	*Linum monogynum*

LOLPER	*Lolium perenne*
LYCVOL	*Lycopodium volubile*
MACEXC	*Macropiper excelsum*
MELRAM	*Melicytus ramiflorus*
METDIF	*Metrosideros diffusa*
MICSTI	*Microlaena stipoides*
MYRAUS	*Myrsine australis*
NERDEP	*Nertera depressa*
OLEPAN	*Olearia paniculata*
OLERAN	*O. rani*
OXAINC	*Oxalis incarnata*
PAESCA	*Paesia scaberula*
PENCOR	*Pennantia corymbosa*
PHOCOO	*Phormium cookianum*
PHYDIV	*Phymatodes diversifolium* (new name - *Microsorum pustulatum*)
PNEPEN	*Pneumatopteris pennigera*
POAANN	*P. scandens*
POLRIC	*Polystichum richardii*
PSEARB	*Pseudopanax arboreus*
PTEESC	*Pteridium esculentum*
RHOSAP	*Rhopalostylis sapida*
RIPSCA	*Ripogonum scandens*
RUMACE	*Rumex acetosella*
RYTRAC	*Rytidosperma racemosum*
SOLAVI	*Solanum aviculare*
SORAUC	*Sorbus acuparia*
TAROFF	*Taraxacum officinale*
TELMON	*Teline monspessulana*
TRIFOL	*Trifolium* spp.
UNCUNC	*Uncinia uncinata*
VERTHA	*Verbascum thapsus*
VICSAT	*Vicia sativa*
WEIRAE	*Weinmannia racemosa*

APPENDIX 5: Weed survey map of Maud Island, locating known populations of old man's beard and gorse, 2001.



APPENDIX 6: Aerial photograph, Maud Island, 1963.



APPENDIX 7: Aerial photograph, Maud Island, 1993.

APPENDIX 8: Aerial photograph, Maud Island, 2000.

APPENDIX 9: G.P.S. locations of photopoints, Maud Island, Dix 1990.

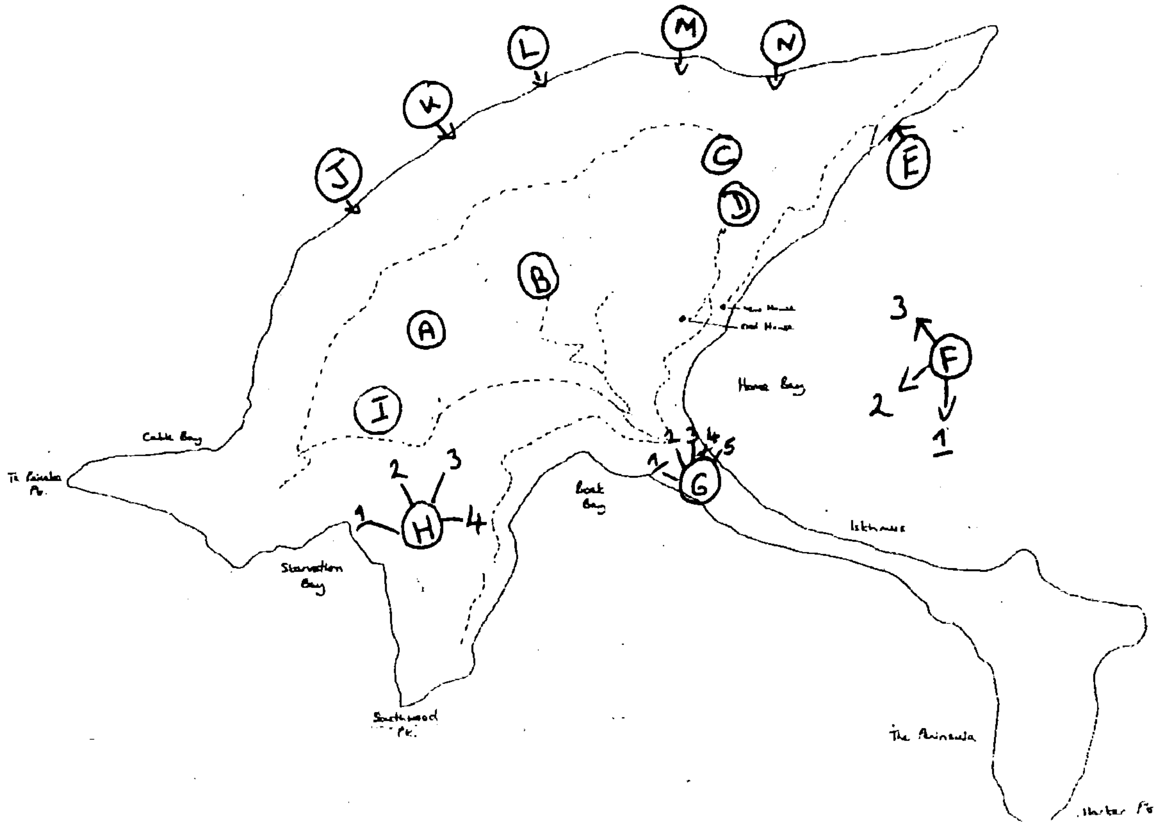
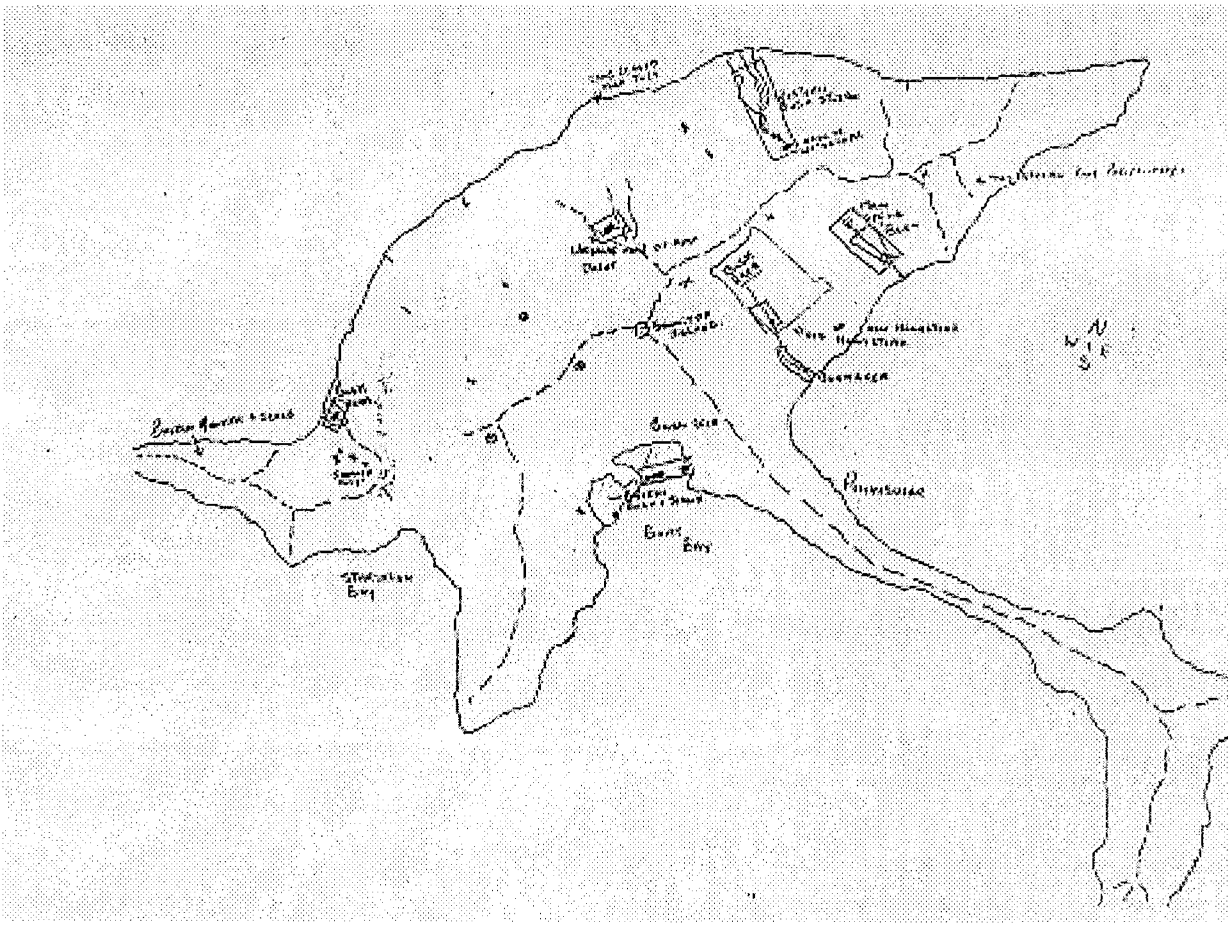


Photo-point	Easting	Northing
A	2584619	6019913
B	2584658	6019967
C	2585495	6029411
D	*	
E	*	
F	2586316	6020419
Note F photo-points taken on boat, just offshore		
G	2585211	6019347
H	2584320	6019257
I	2584210	6019629
J	2583928	6020494
K	2584045	6020567
L	2584637	6020808
M	2585253	6020995
N	2585433	6020943

*GPS points were not obtained at all photo-points

APPENDIX 10: Natural water sources on Maud Island.



Key:

- Watering places with flows of less than 2mm

☐ Permanent supplies

IIII Seepage only

X Kakapo catchments

⊠ Possible catchments

APPENDIX 11: Weather data, Maud Island, 1997-2001.

Days of occurrence: Ground Frost

Year	1997	1998	1999	2000	2001
Jan	20.4		22.5	19.8	20.5
Feb	21.6	22.5	21.5	21.2	22.7
Mar	18.9	20.9	21.2	19.6	20.0
Apr	16.9	18.6	17.7	17.2	17.8
May	15.7	15.4	16.5	15.8	
Jun	12.7	13.1	13.4	13.2	13.6
Jul	11.5	13.7	12.8	13.3	
Aug	12.5	12.5	13.2	13.1	
Sep	12.7	15.4	15.1	14.4	
Oct	16.2	16.0	16.9	16.2	
Nov		17.3	17.6	16.3	
Dec		19.6	18.9	20.4	
Ann		17.2	17.3	16.7	

Days of occurrence: Air Frost

Year	1997	1998	1999	2000	2001
Jan				0	0
Feb	0		0	0	0
Mar	0		0	0	0
Apr		0		0	0
May	0			0	
Jun	0	0	0	0	0
Jul	0	0	0	0	
Aug	0	0	0	0	
Sep	0	0	0	0	
Oct	0	0	0	0	
Nov		0	0	0	
Dec		0	0	0	
Ann				0	

Total rainfall mm

Year	1997	1998	1999	2000	2001
Jan	42.6	204.0	109.3	215.0	18.7
Feb	123.5	71.6	33.4	41.6	5.5
Mar	97.3	136.8	171.4	63.3	48.1
Apr	72.7	68.3	96.3	191.7	59.6
May	75.1	128.1	196.1	144.0	79.5
Jun	125.5	240.0	119.3	189.0	120.3
Jul	122.8	386.8	127.9	59.1	
Aug	115.1	103.0	208.8	179.0	
Sep	135.1	146.5	82.8	126.6	
Oct	161.0	491.2	210.4	161.2	
Nov	58.7	65.9	267.6	33.7	
Dec	162.2	107.1	106.7	76.1	
Ann	1291.6	2149.3	1730.0	1480.3	

Mean daily air temperature Celsius

Year	1997	1998	1999	2000	2001
Jan	20.4		22.5	19.8	20.5
Feb	21.6	22.5	21.5	21.2	22.7
Mar	18.9	20.9	21.2	19.6	20.0
Apr	16.9	18.6	17.7	17.2	17.8
May	15.7	15.4	16.5	15.8	
Jun	12.7	13.1	13.4	13.2	13.6
Jul	11.5	13.7	12.8	13.3	
Aug	12.5	12.5	13.2	13.1	
Sep	12.7	15.4	15.1	14.4	
Oct	16.2	16.0	16.9	16.2	
Nov		17.3	17.6	16.3	
Dec		19.6	18.9	20.4	
Ann		17.2	17.3	16.7	

APPENDIX 12: DDE, DDD and DDT levels in soils, worms, slugs and wekas, Maud Island, 1971 and Organochlorine levels in soil, Maud Island, 1993, Site 1and 2 in paddock above caretaker's house.

Site	DDE	DDD	DDT	Total ppm
Homestead paddocks	1.2	1.2	6.8	9.2
Main Ridge	Traces not significant			
Worms	1.9	0.6	4.4	6.9
Slugs	3.8	2.2	8.5	14.5
Weka 1	5.3	-	-	5.3
Weka 2	8.4	-	-	8.4
Weka 3	33.2	3	-	36.2
Weka 4	41.5	3	-	41.5

	Site 1	Site 2	Kakapo pen No 1
Arsenic	9.5	14.8	5.7
Lead	41.5	12.4	1.4
DDT	0.33	0.27	17.2
Dieldrin	0.07	0.63	-